CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

This chapter provides the technical support documentation for the engineering analyses of general service fluorescent lamps (GSFL) and incandescent reflector lamps (IRL). Generally, the purpose of the engineering analysis is to develop efficacy levels (ELs) that encompass the range of products affected by a standard, from the baseline products to the maximum technologically feasible products, and develop power rating estimates for the products analyzed. The outputs from the engineering analysis are critical inputs to subsequent cost-benefit calculations for individual consumers.

The engineering analysis follows the screening analysis (chapter 4), in which the U.S. Department of Energy (DOE) identifies design options that are later used for the rulemaking analyses. Design options include discrete technologies, such as krypton fill gas, that improve efficacy. DOE develops product efficacy levels associated with lamp designs that incorporate a range of design options.

While some engineering analyses for other rulemakings discuss manufacturer production costs or selling prices and relate cost or price to efficacy, this engineering analysis does not address manufacturer costs or mark-ups. In this rulemaking, DOE develops end-user prices for lamp and lamp-and-ballast designs analyzed by discounting published list prices (i.e., “blue book pricing”). The product price determination (chapter 7) discusses the pricing methodology and results. By combining the results of the engineering analysis and the product price determination, DOE derives the necessary inputs for use in the life-cycle cost (LCC) analysis and national impacts analysis (NIA). In particular, DOE develops lamp and lamp-and-ballast designs associated with particular ELs and end-user prices.

This chapter starts with an outline of the engineering analysis (section 5.2), followed by specifics on the engineering analysis for GSFL (section 5.3) and IRL (section 5.4). Each section provides detailed information on the baseline lamps and representative product classes DOE chooses to analyze, the development of ELs, and the results of the engineering analysis. Section 5.5 discusses how DOE extends its results from the representative product classes to those products it does not analyze.

5.2 ENGINEERING ANALYSIS FRAMEWORK

To the extent possible, DOE bases the engineering analysis on commercially-available lamps that incorporate the design options identified in the technology assessment and screening analysis (chapter 4). For GSFL and IRL, DOE also bases the majority of the engineering analysis on commercially available lamps. However, where needed, DOE supplements these lamps with additional model lamps that use commercially-available technologies.

The engineering analysis for each of the two categories of lamps DOE analyzes in this rulemaking (i.e., GSFL and IRL) follows a similar approach:

Step 1. *Representative Product Classes*. DOE reviews covered lamps and the associated product classes. When a product has multiple product classes, DOE selects certain classes as "representative" and concentrates its analytical effort on these. DOE selects representative product classes primarily because of their high market volumes. Section 5.5 discusses how DOE extrapolated from representative product classes to other product classes.

Step 2. *Baseline Lamps*. DOE selects baseline lamps from the representative product classes. Generally, a baseline lamp is one that just meets existing mandatory energy conservation standards or represents the typical lamp sold. DOE selects specific characteristics such as certain correlated color temperatures (CCTs), operating lifetimes, and light outputs to characterize the most common lamps consumers purchase. DOE selects multiple baseline lamps in each product class to ensure consideration of different high-volume lamps and their associated consumer economics.

Step 3. *Lamp-and-Ballast Designs*. DOE selects more efficacious lamps for each baseline lamp in the representative product classes by considering technologies not eliminated in the screening analysis. DOE considers these technologies either explicitly as design options or implicitly as design options incorporated into commercially-available lamps at the efficacy levels evaluated. In identifying more efficacious lamp-and-ballast designs, DOE recognizes that a lamp's lumen package and performance characteristics are important design criteria for consumers. For example, if consumers do not have the option to purchase substitution lamps or lamp-and-ballast systems with similar lumen packages under an energy conservation standard, consumers would need to change the lighting design to maintain a similar light output. Therefore, DOE establishes lamp-and-ballast designs for the engineering analysis so that potential light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system. DOE also chooses substitute lamps with performance characteristics similar to those of the baseline lamps.

In identifying more efficacious substitutes, DOE uses a database of commercially-available lamps. For GSFL, DOE develops the engineering analysis based on two substitution cases in which consumers can maintain light output while decreasing energy consumption. In the first case, the consumer replaces the baseline lamp with a more-efficacious, lower-wattage lamp that operates on the existing ballast. In the second case, the consumer replaces the lamp-and-ballast system with a more-efficacious same- or lower-wattage lamp and a different ballast. For example, a lamp-and-ballast system with a more efficacious, same-wattage lamp and lower ballast factor[a] (BF) ballast will consume less energy and maintain light output.

For IRL, DOE uses some commercially-available lamps, but also developed "model" lamps. These models incorporate designs that may not be commercially available for certain lamp types and wattages, but use commercially-available technologies.

Step 4. *Efficacy Levels*. After identifying the more efficacious substitutes for each baseline lamp or lamp-and-ballast system, DOE develops ELs based on three factors: (1) the design options associated with the specific lamps being studied (e.g., grades of phosphor for fluorescent lamps, the use of halogen capsules for IRL, etc.); (2) the ability of lamps across wattages to comply with the EL of a given product class;[b] and (3) the maximum technologically-feasible efficacy level.

The sections that follow discuss how DOE applies this methodology to each product class to create the engineering analysis.

5.3 GENERAL SERVICE FLUORESCENT LAMPS

As discussed in the market and technology assessment (chapter 3), DOE revised the Energy Policy and Conservation Act (EPCA) table of standards for fluorescent lamps to twelve product classes, as shown in Table 5.3.1. Of these twelve product classes, DOE chose to analyze the five classes that represent high shipment volumes–4-foot medium bipin (MBP), 8-foot single pin (SP) slimline, 8-foot recessed double contact (RDC) high output (HO), 4-foot miniature bipin (MiniBP) standard output (SO), and 4-foot MiniBP HO –all with a CCT less than or equal to 4,500 Kelvin (K). The 4-foot MBP lamps constitute the vast majority of GSFL sales. These are followed, in order of unit sales, by 8-foot SP slimline lamps and 8-foot RDC HO lamps. Shipments of 2-foot U-shaped lamps have accounted for less than five percent of GSFL unit sales historically and have remained stable at that level.[1] Given the relatively small market share of U-shaped lamps, DOE did not explicitly analyze these lamps. While total shipments of 4-foot MiniBP SO and HO lamps (often referred to as T5 lamps) currently have a relatively small market share, shipment trends indicate that the market for these lamps is rapidly increasing. Therefore, DOE directly analyzed 4-foot MiniBP SO and 4-foot MiniBP HO lamps.. In addition, as lamps with CCTs greater than 4,500K represent small market shares of total GSFL sales, DOE only analyzed lamps with CCTs less than or equal to 4,500K. DOE discusses each of the five representative product classes separately in the sections that follow.

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[a] The "ballast factor" of a ballast is the ratio of the light output of a fluorescent lamp or lamps operated on a ballast to the light output of the lamp(s) operated on a reference ballast. Ballast factor depends on both the ballast and the lamp type; a single ballast can have several ballast factors depending on lamp type. The light output of a single fluorescent lamp is measured on a ballast with a ballast factor of 1.0. One can reduce the light output of a lamp-and-ballast system by operating a lamp on a ballast with a lower ballast factor.

[b] Efficacy levels span multiple lamps of different wattages. In selecting ELs, DOE considered whether lamps of different wattages can meet the efficacy levels prescribed by those ELs.

Although DOE did not create a separate engineering analysis for 2-foot U-shaped lamps or lamps that have a CCT greater than 4,500K, DOE established standards for these product classes, based on the representative product classes directly analyzed. For instance, DOE extended its proposal for the 4-foot MBP product class to the 2-foot U-shaped product class. This was possible because 2-foot U-shaped lamps generally operate in the same way and typically span the same wattages as 4-foot MBP lamps. For lamps with CCTs greater than 4,500K, DOE extended proposed standards from similar lamp types with a CCT of less than or equal to 4,500K as they operate in a similar fashion and generally span the same wattages. Section 5.5 provides more information on extending standards to the product classes DOE did not analyze.

Table 5.3.1 DOE Final Rule Product Classes for General Service Fluorescent Lamps

Lamp Type	**For CCT ≤ 4,500K Minimum Lamp Efficacy** *lm/W**	**For CCT > 4,500K Minimum Lamp Efficacy** *lm/W*
4-foot MBP	Representative product class	Scaled from ≤4,500K
2-foot U-shaped	Scaled from 4-foot MBP	Scaled from ≤4,500K
8-foot SP slimline	Representative product class	Scaled from ≤4,500K
8-foot RDC HO	Representative product class	Scaled from ≤4,500K
4-foot T5 MiniBP SO	Representative product class	Scaled from ≤ 4,500K
4-foot T5 MiniBP HO	Representative product class	Scaled from ≤ 4,500K

* lm/W = lumens per watt

In the engineering analysis for GSFL, DOE based its ELs on lamps because the energy conservation standards only apply to lamps. However, DOE used a systems approach in analyzing these representative product classes because both lamps and ballasts determine a system's energy use and light output. DOE paired a lamp with a ballast to develop lamp-and-ballast systems. By using a systems approach, DOE was able to demonstrate the actual energy consumption and light output of an operating lamp.

Using this systems approach, DOE selected a variety of energy-saving lamp-and-ballast systems per EL. In general, DOE chose its lamp designs (which refer to lamp substitution options) and lamp-and-ballast designs (which refer to lamp-and-ballast substitution options) by selecting commercially-available fluorescent lamps at higher efficacies than the baseline lamps. Higher efficacies are achieved through a variety of technologies. As discussed in the screening analysis (chapter 4), DOE considered commercially available GSFL that use highly-emissive electrode coatings, higher-efficacy lamp fill gas composition, higher-efficacy phosphors, glass coatings, or higher-efficacy lamp diameter to achieve higher-efficacy lamp designs.

For the LCC, DOE analyzed lamp-and-ballast systems that both save energy and maintain comparable light output. In particular, DOE considered lamp-and-ballast designs that emit mean lumens equal to, greater than, or no more than 10 percent less than the light output of the baseline system. DOE maintained light output across efficacy levels to ensure that products supply equivalent service in the base case and standards case.

In assessing light output, DOE made a distinction between mean and initial lumens. DOE used initial lumens in its test procedures to measure compliance with a standard. This is consistent with consensus industry standards on efficacy measurements. Therefore, DOE used initial lumens to calculate ELs. However, the light output of a lamp decreases over time. To account for this real-world depreciation in lumens, DOE used mean lumens to determine equivalent substitutes in the LCC and to determine the light output of GSFL in the NIA.

For GSFL, energy savings can be achieved either through lamp replacements or lamp-and-ballast replacements. For lamp replacements, DOE analyzed reduced-wattage, higher-efficacy lamps for use on the existing ballast. For lamp-and-ballast replacements, DOE used a variety of lamp-and-ballast combinations to obtain energy savings and maintain comparable mean lumens. These combinations included both reduced-wattage lamps and same-wattage lamps. For example, energy savings could be achieved using a same-wattage, higher-efficacy lamp with a lower BF ballast while maintaining mean lumen output.

Some consumers may operate non-energy-saving systems. For example, a consumer who pairs a same-wattage, higher-efficacy lamp with an existing ballast will get more light output but will not save energy. DOE did not consider such non-energy-saving systems in the LCC because energy savings determine whether a consumer can recoup any higher first costs of replacement products. However, DOE did take into account the use of both energy-saving and non-energy-saving systems as well as systems that may over- or under-light when aggregating market behavior in the NIA. This reflects the fact that DOE cannot require consumers to change their ballast along with their lamp. Appendix 5A shows lamp-and-ballast designs considered in the NIA.

Because DOE is using a systems approach, the system power rating is an important result of the engineering analysis. The system power rating represents the energy consumption rate of both the lamp and ballast, and therefore is greater than the rated power of the lamp alone. While the rated lamp power affects the system power, the system power is also affected by the type of ballast used, the BF of that ballast, and the number of lamps operated per ballast.

DOE calculated the system power data using published catalog information. For each lamp wattage and ballast type, DOE linearly fitted the system power rating of a lamp on several different ballasts with varying ballast factors. DOE used this linear fit to derive the system power rating of the lamp on the ballasts used in the analysis. The linear fit follows the equation below:

$$SPR = m * BF + b \qquad \textbf{Eq. 5.1}$$

where:

SPR	=	System Power Rating
BF	=	Ballast Factor
m	=	Slope of Linear Fit
b	=	Y-Intercept of Linear Fit

DOE considered both magnetic and electronic ballasts. For 4-foot T8 and 4-foot T12 systems, DOE used system power data from manufacturer literature to develop a linear fit for lamps on three-lamp and two-lamp, 120V, electronic instant-start ballasts with similar ballast efficacy factors (BEF).[c] For some 4-foot T12s, DOE also used one-lamp and two-lamp 120V, magnetic, rapid-start ballasts with common ballast efficacy factors. A linear fit was not necessary for these magnetic systems because DOE used only one type of magnetic ballast in the analysis. For 8-foot T8 and 8-foot T12 SP slimline and RDC HO lamps, DOE used system power data from manufacturer literature to develop a linear fit for lamps on two-lamp, 120V, electronic instant-start ballasts. DOE also used data for some 8-foot T12 SP slimline and RDC HO lamps on two-lamp, 120V, magnetic, instant-start ballasts. Again, a linear fit is not necessary for the magnetic systems because DOE used only one ballast per lamp type in the analysis. For T5 lamps, DOE used system power data from manufacturer literature to develop a linear fit for lamps on a two-lamp, 120V, electronic programmed-start ballast.

5.3.1 Four-Foot MBP GSFL With CCTs ≤ 4,500K

DOE selected the 4-foot MBP with CCTs less than or equal to 4,500K product class as a representative product class for GSFL because it has the highest volume shipments of all the product classes for fluorescent lamps. DOE reviewed the range of commercially available lamp-and-ballast combinations to pair each lamp it analyzed with a ballast. DOE found that ballasts for 4-foot MBP ballasts are available in a variety of lamp-per-ballast designs. For example, electronic ballasts are typically manufactured in one-, two-, three-, and four-lamp versions. According to the 2000 rule on GSFL ballasts ("2000 Ballast Rule"),[2] there are on average 2.8 lamps per 4-foot MBP system. 62 FR 56740 (September 19, 2000). To most accurately represent the market and simplify the analysis, DOE used a three-lamp system for 4-foot MBP lamps operating on electronic ballasts in the commercial sector. (This decision effectively spreads the cost of a new ballast over the average number of lamps per system). To make a comparison between electronic and magnetic 4-foot MBP systems, and because three-lamp magnetic ballasts typically are not sold, DOE developed a system that combines a two-lamp magnetic and one-lamp magnetic ballast. This allowed DOE to compare similar light output packages and make a level comparison on energy use.[d] As a review of manufacturer catalogs indicated that two-lamp ballasts were most prevalent in the residential sector, DOE developed a separate engineering analysis for 4-foot MBP lamps in the residential sector based on these two-lamp systems.

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[c] Energy-efficient ballasts are characterized as having higher ballast efficacy factors (BEF). The BEF is directly related to the quotient of the BF and the power consumed by the ballast, such that a ballast maintaining BF while reducing power consumption will have a higher BEF and be a more energy-efficient ballast. In its analysis, DOE varied the ballast BF, not the BEF (given the same lamp wattage and ballast type ("electronic" or "magnetic")), in its assessment of standards for fluorescent lamps. DOE will be considering new and amended BEF standards in a separate fluorescent lamp ballast rulemaking.

[d] DOE recognizes that the combined cost of a one-lamp and two-lamp magnetic system would be higher than the cost of a three-lamp system if it were manufactured. However, the comparative economics between a one-lamp and two-lamp magnetic ballast versus a three-lamp electronic ballast is not an issue in DOE's calculation of the LCC. Since ballast standards will be effective in 2010 for non-residential 4-foot ballasts, DOE assumes that all new 4-foot non-residential ballast sales are electronic.

5.3.1.1 Baseline Models

The 4-foot MBP product class represents high-volume T12 and T8 4-foot MBP lamps operating on various ballasts. To reflect the most common lamp and wattage combinations for this product class in the commercial and industrial sectors, DOE selected three baseline lamp/wattage combinations: a 32W T8, a 34W T12, and a 40W T12 lamp. In 2005, T8 lamps represented 57 percent of the 4-foot MBP shipments, of which the 32W lamp was the most common. The 2005 shipments of 4-foot T12 lamps represented 43 percent of all 4-foot MBP shipments. The 34W T12 lamp comprised approximately two-thirds of these shipments and the 40W T12 was approximately one-third. Therefore, these three baseline lamps represent the three highest volume lamp diameter and wattage combinations for the 4-foot MBP product class in the commercial and industrial sectors. DOE also found that a significant portion of T12, 4-foot MBP lamps operate in the residential sector. Conversations with industry experts as well as a published study prepared for the utility Pacific Gas & Electric (PG&E[3]) revealed that residential consumers are most likely to buy a 40W T12 lamp; 32W T8 lamps and 34W T12 lamps are less common. Therefore, in the residential sector, DOE only analyzed the 40W T12 lamp as a baseline lamp.

For each of these baseline model lamps, DOE developed a set of typical performance characteristics. For the 32W 4-foot T8 MBP lamp, DOE selected a lamp using a 700 series rare earth phosphor. These lamps typically have a color rendering index (CRI) of 70 to 79. During discussions with industry experts, DOE found that this lamp represents the majority of 4-foot T8 MBP lamps sold. Typically, a baseline product is a unit that just meets the existing energy conservation standard for that product (75.0 lm/W for this product class). However, there are no T8 lamps in this product class with an efficacy as low as 75.0 lm/W. Therefore, DOE selected a lamp with an efficacy of 86.2 lm/W because it is the most common T8 lamp sold. For new system installations, DOE selected T8 lamps operating in three-lamp fixtures. These fixtures are assumed to operate on a 120V instant-start electronic ballast with a 0.88 BF. Together, the lamp-and-ballast combination in this three-lamp system has a light emission of approximately 6,650 mean lumens (and 7,390 initial lumens) when operating with the baseline lamp.

For the 34W 4-foot T12 MBP lamp, DOE selected a cool white lamp with an efficacy that is slightly above the minimum efficacy standard (77.9 lm/W). A review of the product catalogs found there are no covered 34W 4-foot T12 MBP lamps that are just compliant with the standard (75.0 lm/W), or any with an efficacy between 75.0 and 77.9 lm/W. For the 40W 4-foot T12 MBP lamp in the commercial and industrial sectors, DOE selected a lamp using 700 series rare earth phosphor and an efficacy of 78 lm/W. DOE paired both commercial and industrial 4-foot T12 MBP lamps with a rapid-start 120V magnetic ballast, which exhibits a 0.88 BF when operating the 34W lamp and a 0.95 BF when operating the 40W lamp. This combination of lamp and ballast represents the most common configuration for this lamp in existing and new installations. Together, this lamp-and-ballast combination in a three-lamp fixture creates a system package of over 6,070 mean lumens (and nearly 7,000 initial lumens) for the baseline 34W lamps and approximately 8,210 mean lumens (and 9,120 initial lumens) for the baseline 40W lamps. As mentioned earlier, DOE assumed the three-lamp fixture is wired using two magnetic ballasts – a one-lamp and a two-lamp ballast connected in tandem with an adjacent fixture.

In the residential sector, DOE only analyzed the 40W 4-foot T12 MBP lamp as a baseline lamp. After reviewing available catalog information, DOE found that the most common 40W T12 lamp sold in the residential sector is different from the 40W T12 baseline lamp for the commercial and industrial sectors. DOE chose a 40W 4-foot T12 MBP baseline lamp for the residential sector that has a slightly lower efficacy and shorter lifetime than the typical 40W T12 lamp sold in the commercial sector: 76.8 lm/W and 15,000 hours. A review of catalog information and a PG&E study revealed that the most common residential sector ballast is a low-power factor 2-lamp magnetic rapid-start T12 system with a ballast factor of 0.68.[3]

For all baseline lamps and the more efficacious lamp designs, DOE analyzed fluorescent lamps with a CCT of 4,100K. DOE selected this CCT because it represents the highest volume CCT for this category of lamps and because it falls within the CCT span of the analyzed product class (2,500K to 4,500K). Additionally, the typical lifetime for the three baseline models for this product class in the commercial and industrial sectors is 20,000 hours (using a 3-hour on-off testing cycle). In the residential sector, the typical lifetime was found to be 15,000 hours (using a 3-hour on-off testing cycle). While there are lamps in this product class that have other lifetimes under the 3 hour on-off testing cycle, such as 18,000 or 24,000 hrs, these lamps do not represent the typical unit sold for these three lamp types.

Table 5.3.2 Baseline Lamps for Commercial and Industrial 4-Foot MBP Engineering Analysis

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*lm*	*hr*
T12	40	70	4,100	78.0	3,200	2,880	20,000
T12	34	62	4,100	77.9	2,650	2,300	20,000
T8	32	75	4,100	86.2	2,800	2,520	20,000

* Rated efficacy is based on the rated wattage of the lamps, which for T12 lamps is 41W and 34W and for the 32W T8 lamp is 32.5W.

Table 5.3.3 Baseline Lamps for Residential 4-Foot MBP Engineering Analysis

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*lm*	*hr*
T12	40	70	4,100	76.8	3,150	2,860	15,000

* Rated efficacy is based on the rated wattage of the lamps, which for T12 lamps is 41W.

5.3.1.2 Efficacy Levels

For the 4-foot MBP with CCTs less than or equal to 4,500K product class, DOE established ELs around design options that are consistent across all baseline lamps. Because these lamps have different efficacy values and some represent various design options, some ELs affect only three of the four baseline lamps. However, the full range of ELs ultimately specifies requirements that are above the efficacy values of all the baseline lamps sold, and therefore affect all four baseline lamps.

In selecting ELs, DOE considered two different paths to energy savings. The first involves reduced-wattage replacement lamps that could be installed in a socket and operate on the existing ballast. These lower-wattage replacement lamps have a higher efficacy and therefore produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system).

The other path to energy savings involves lamps that have the same or lower wattage in comparison with the baseline lamp, but operate on a new ballast with a different BF so the system power rating is lower. DOE selected a ballast with a particular BF in conjunction with the more efficacious lamp to produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system).

Below is a summary of the ELs considered for 4-foot MBP lamps. The following discussion identifies the steps and technologies associated with each EL DOE considered. As discussed in the screening analysis (chapter 4), DOE used design options that achieve a higher efficacy with highly-emissive electrode coatings, higher-efficacy lamp fill gas composition, higher-efficacy phosphors, glass coatings, or higher-efficacy lamp diameter. Because high-efficacy phosphors and lamp diameter are common methods to achieve higher efficacies, DOE identified the diameter and phosphor associated with each EL:

EL1. This level affects the three T12 baseline lamps. Because the baseline T8 lamp is above this efficacy level, consumers using the T8 lamp are not affected. The 34W T12 moves from a cool white halophosphor to a 700 series rare earth phosphor. The 40W T12 lamp moves from the 700 series rare earth to either an improved 700 series rare earth phosphor or 800 series lamp.

EL2. This level also only affects T12 lamps. For the 34W T12, the lamps change from 700 series to 800 series rare earth phosphor. The 40W T12 lamp at this level uses a premium 800 series rare earth phosphor.

EL3. This level affects all four baseline lamps. The 32W T8 lamp that used 700 series rare earth phosphor in the baseline migrates to an 800 series rare earth phosphor in a 32W lamp. The 34W T12 lamp uses an 800 series rare earth phosphor, and may incorporate other design options to enhance efficacy, such as a different gas fill or increased thickness of the bulb-wall phosphor. At this level there are no 40W T12 lamps that are commercially available.

EL4. This level affects all four baseline lamps. No 4,100K T12 lamps are commercially available that meet this efficacy requirement. Therefore, users of T12 lamps would be forced to replace their ballasts and operate T8 lamps instead. This level requires the use of an improved 800 series rare earth phosphor in full-wattage (32W) T8 lamps. A 30W T8 and 25W T8 lamp that produces an equivalent amount of light as the baseline unit on a similar ballast meet this EL.

EL5. This level affects all three baseline lamps. However, no T12 lamps that can meet this efficacy requirement are commercially available. Therefore, users of T12 lamps would be forced to replace their ballasts and operate T8 lamps instead. For the T8 lamps, this level represents "max-tech," the highest efficacy level available today. It uses premium 800 series rare earth phosphor and may incorporate other efficacy improvements, such as a different gas fill or increased thickness of the bulb-wall phosphor. The 28W T8 lamp that produces an equivalent amount of light on the same ballast as the baseline unit meets this EL.

DOE then developed five initial ELs based on catalog values of commercially-available fluorescent lamps that DOE selected to analyze. Figure 5.3.1 illustrates the five initial ELs on a plot of the efficacies of these lamps vs. their rated wattages. A line at 75 lm/W denotes the existing energy conservation standard (from the Energy Policy Act of 1992 (EPACT 1992)). Square boxes and labels identify the four baseline lamps. The plot also shows replacement lamps DOE considered for each lamp at higher efficacies. Some lamps are at the same wattage, but have a higher efficacy; others have a combination of lower wattage and higher efficacy so that the lamp-and-ballast system produces light output no less than 10 percent of the baseline.

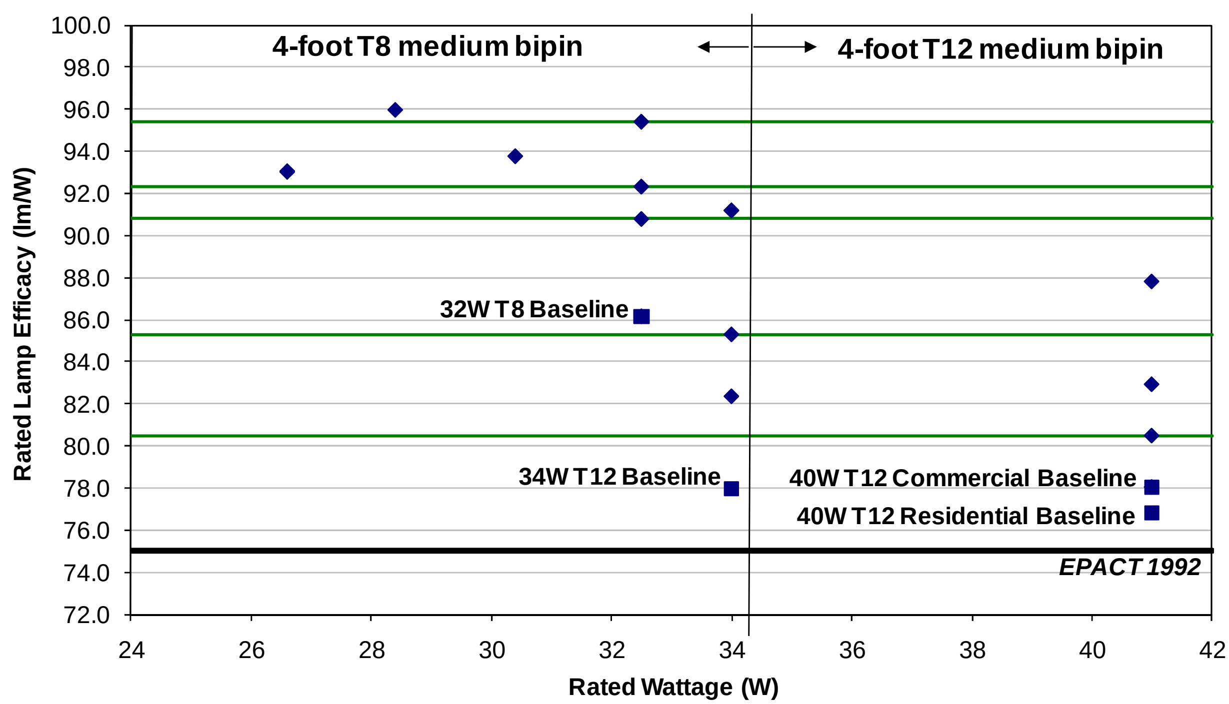

Figure 5.3.1 Initial Efficacy Levels for 4-Foot MBP Fluorescent Lamps With CCTs ≤ 4,500K

Table 5.3.4 provides detailed information on the 4-foot MBP lamp designs used in the engineering analysis and subsequent analyses.

Table 5.3.4 4-Foot MBP Lamp Designs

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	CRI
		W	*W*	*lm/W*	*lm*	*lm*	*hr*	
Baseline/0*	T12	40	41.0	76.8	3,150	2,860	15,000	70
Baseline/0**	T12	40	41.0	78.0	3,200	2,880	20,000	70
Baseline/0**	T12	34	34.0	77.9	2,650	2,300	20,000	62
1	T12	40	41.0	80.5	3,300	3,000	20,000	80
1	T12	34	34.0	82.4	2,800	2,460	20,000	70
1	T12	40	41.0	82.9	3,400	3,060	24,000	80
2	T12	34	34.0	85.3	2,900	2,610	20,000	80
Baseline/2	T8	32	32.5	86.2	2,800	2,520	20,000	75
2	T12	40	41.0	87.8	3,600	3,250	24,000	85
3	T8	32	32.5	90.8	2,950	2,710	20,000	82
3	T12	34	34.0	91.2	3,100	2,790	24,000	85
4	T8	32	32.5	92.3	3,000	2,850	24,000	85
4	T8	25	26.6	93.0	2,475	2,350	30,000	85
4	T8	30	30.4	93.8	2,850	2,680	20,000	82
5	T8	32	32.5	95.4	3,100	2,915	24,000	82
5	T8	28	28.4	96.0	2,725	2,560	18,000	82
*This baseline lamp is used only in the residential sector. **These baseline lamps are used only in the commercial and industrial sectors.								

As seen above, DOE used commercially-available lamps and their associated rated efficacies (rated initial lumen output divided by the ANSI rated wattage) to determine the design options required to meet each efficacy level. However, to establish the minimum efficacy requirements for each efficacy level, DOE coupled catalog data on commercially-available lamps with data submitted to DOE by manufacturers for the purpose of compliance with existing energy conservation standards for general service fluorescent lamps. By analyzing manufacturer compliance reports, DOE found that efficacies of lamps when reported for the purpose of compliance often vary from catalog-rated values. Because the test procedures for GSFL incorporate a tolerance factor comparing measured lamp wattage to ANSI-rated wattage, the measured efficacy of the lamps may be significantly different from the rated efficacy. In addition, using rated lamp efficacy does not account for lot-to-lot production variability which does affect the efficacy at which the lamps comply. As the efficacy reported for compliance is related to the lower limit of the 95-percent confidence interval, significant variability in production may result in compliance efficacies that are lower than rated efficacies.

For these reasons, to establish GSFL minimum efficacy requirements associated with each efficacy level, DOE used lamp efficacy values submitted to DOE for the purpose of compliance with existing energy conservation standards. Specifically, DOE determined the compliance efficacies of commercially-available lamps used in the engineering analysis. For example, as seen in Figure 5.3.1, DOE established EL2 such that three specific lamps comply:

the baseline 32W T8 lamp, the 34W T12 800 series lamp with initial lumen output of 3,100 lumens, and the 40W T12 800 series lamps with initial lumen output of 3,250 lumens. Through examining compliance report data, DOE found that the 34W T12 lamp had the lowest compliance efficacy of the three (81 lm/W), and therefore, set EL2 at 81 lm/W. Because DOE did not have compliance report data on every lamp design analyzed, in such situations DOE used compliance report data of lamps with similar design options to determine the appropriate minimum efficacy requirement. Figure 5.3.2 below shows all compliance report data for 4-foot MBP lamps with CCTs less than or equal to 4,500K.

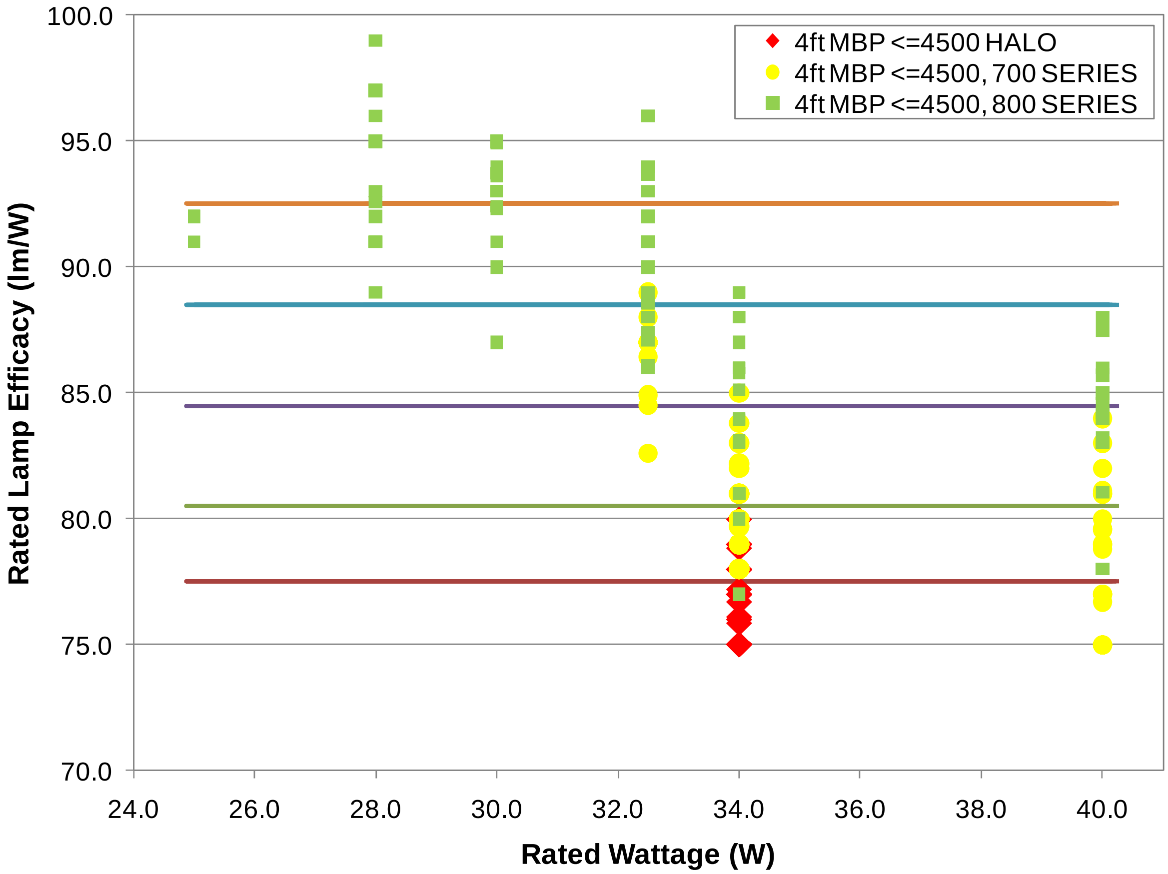

Figure 5.3.2 All Compliance Report Data for 4-Foot MBP Fluorescent Lamps with CCTs ≤ 4,500K

Although DOE obtained compliance reports submitted over the past 15 years, DOE only considered the most recent data when verifying efficacy levels. DOE believes that data contained in compliance reports submitted 2007 and 2008 accurately account for adjustments over the past 15 years to photometry facilities used for NIST and NVLAP testing that may have resulted in a reduction of reported lumens for some products. Figure 5.3.3 only shows compliance report data submitted in 2007 and 2008 for 4-foot MBP lamps with CCTs less than or equal to 4,500K.

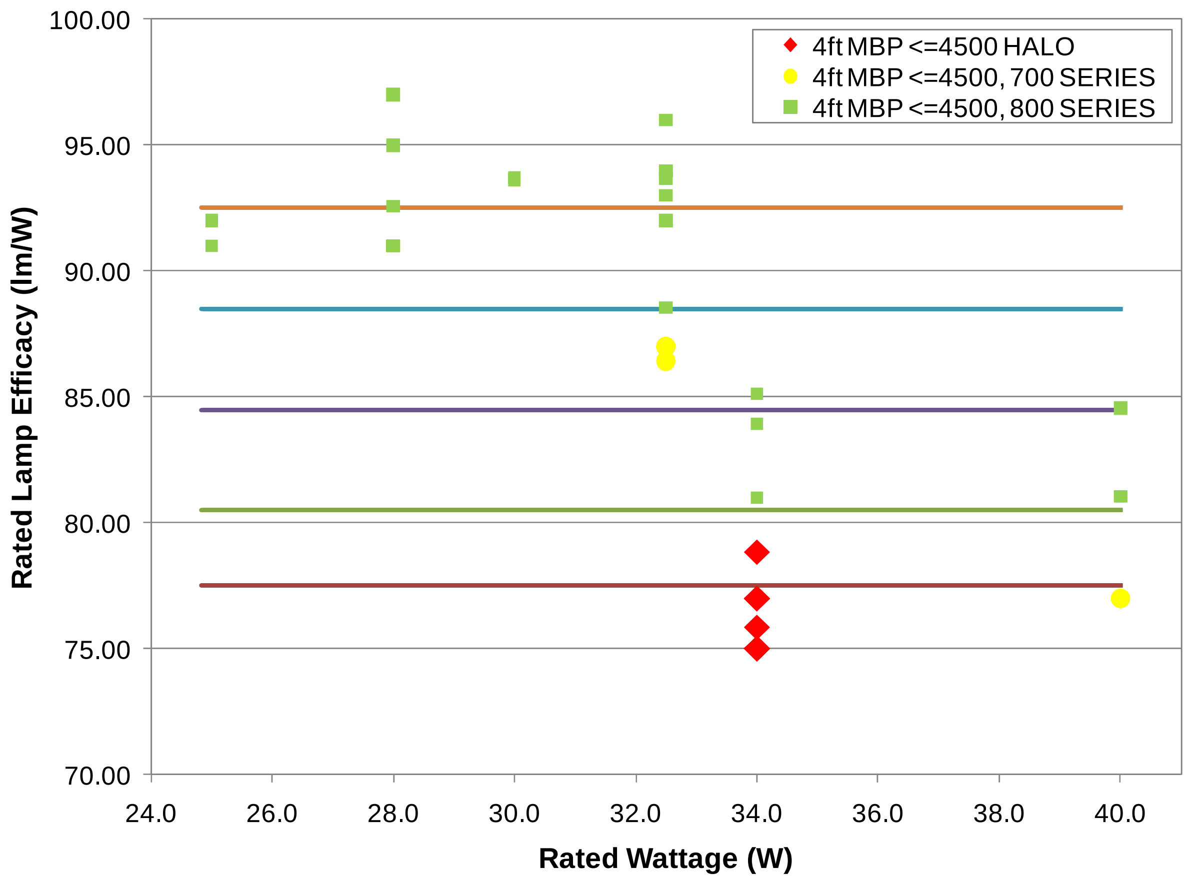

Figure 5.3.3 2007 and 2008 Compliance Report Data for 4-Foot MBP Fluorescent Lamps with CCTs ≤ 4,500K

Table 5.3.5 summarizes the resulting efficacy requirements at each level, after accounting for compliance report data, for 4-foot MBP lamps with CCTs less than or equal to 4,500K.

Table 5.3.5 Summary of the ELs for 4-Foot MBP Fluorescent Lamps With CCTs ≤ 4,500K

Efficacy Level	**Efficacy Requirement** *lm/W*
EL1	78
EL2	81
EL3	85
EL4	89
EL5	93

Section 5.3.1.4 provides additional information on the lamp-and-ballast systems DOE uses in the engineering analysis.

5.3.1.3 System Power Rating

The system power rating is an important result of the engineering analysis. DOE calculated the system power rating, which represents the energy consumption rate of the lamps in combination with a ballast, using published catalog information. For each lamp wattage and ballast type, DOE applied a linear fit to several points identifying the system power rating of a lamp on a ballast and the ballast factor of the ballast. The fit follows the form of Eq. 5.1 where $SPR = m * BF + b$. DOE used a linear form because the relationship is approximately linear over the range of BFs and wattages considered.

The ballasts DOE used typically have a total harmonic distortion (THD) less than 20 percent, power factors (PF) greater than 0.95, and typical ballast efficacy factors. Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages. Also, because there is less manufacturer literature on system power ratings of ballasts with lower wattage lamps, DOE used fewer points to develop a linear fit for the energy-saving lamp wattages. Figure 5.3.4 to Figure 5.3.7 show the linear fit and ballast characteristics DOE uses to derive the system power rating for 3-lamp, 4-foot T8 lamps on electronic ballasts.

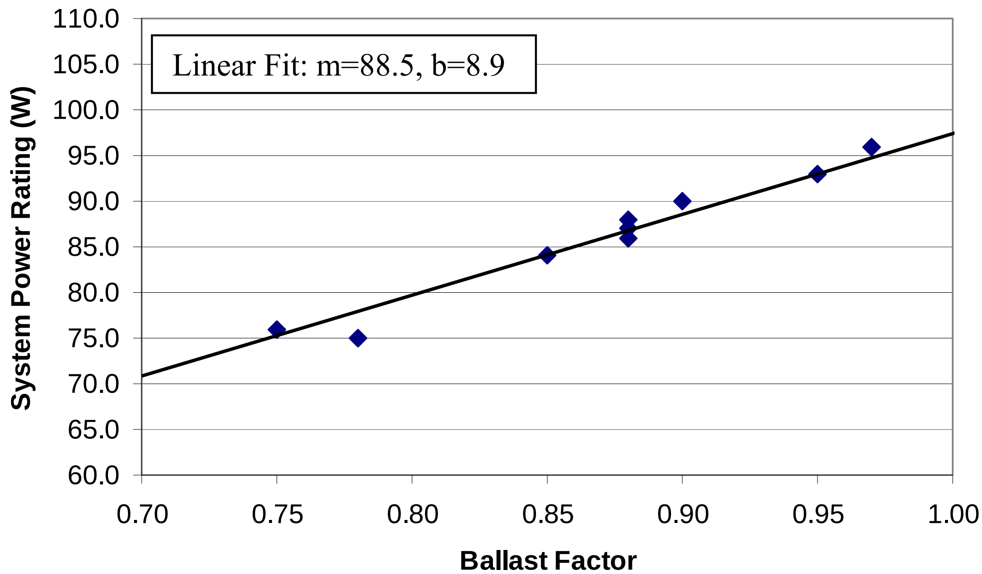

Figure 5.3.4 Three-Lamp 32W T8 120V Ballasts with THD <20 Percent, PF >0.95, and BEF 0.98-1.05

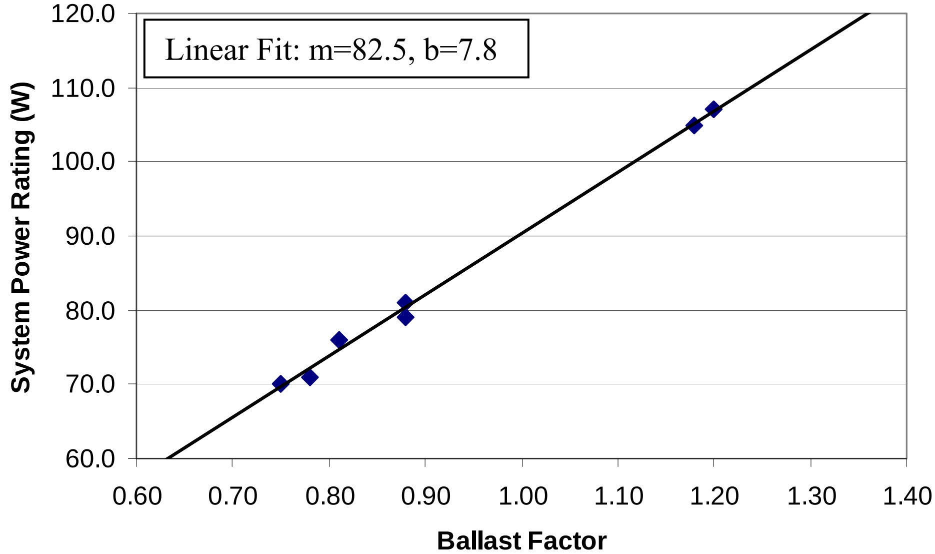

Figure 5.3.5 Three-Lamp 30W T8 120V Ballasts with THD <20 Percent, PF >0.95, and BEF 1.07-1.12

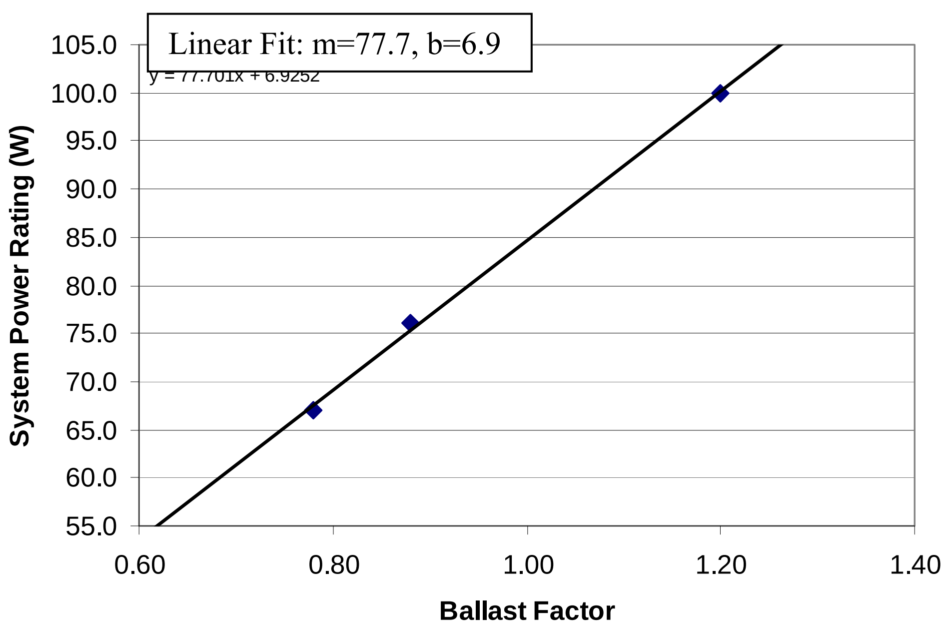

Figure 5.3.6 Three-Lamp 28W T8 120V Ballasts with THD <20 Percent, PF >0.98, and BEF 1.16-1.20

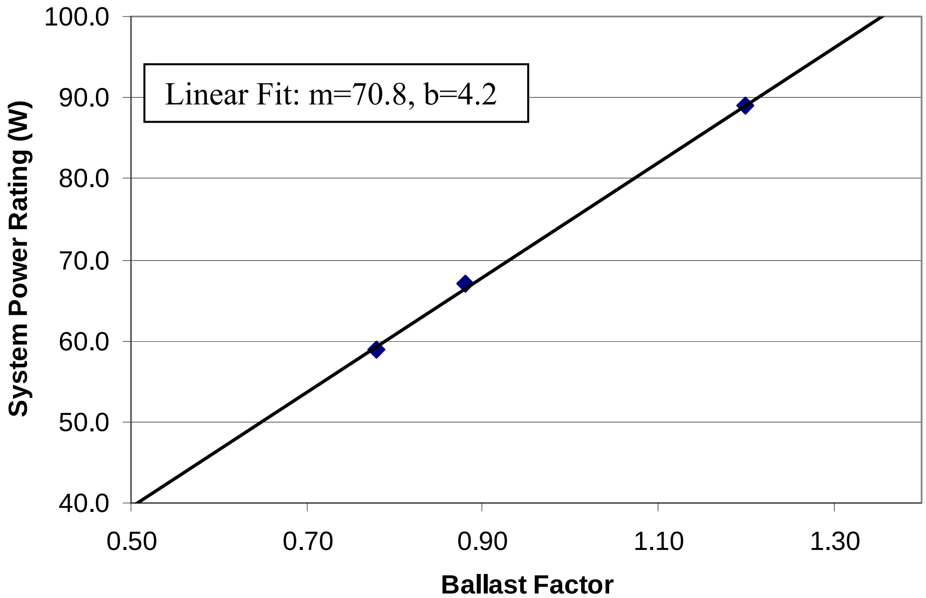

Figure 5.3.7 Three-Lamp 25W T8 120V Ballasts with THD <20 Percent, and BEF 1.31-1.34

Figure 5.3.8 to Figure 5.3.11 show the linear fit and ballast characteristics DOE used to derive the system power rating for two-lamp, 4-foot T8 MBP lamps on electronic ballasts DOE used the system power rating for these ballasts to derive both the system power rating for 4-foot T8 systems in the residential sector, 4-foot T12 electronically ballasted systems and for additional systems DOE used in the national impact analysis. The ballasts DOE used typically have a THD less than 20 percent, PFs greater than 0.95, and typical BEFs. Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages. Also, because there is less manufacturer literature on system power ratings of ballasts with lower wattage lamps, DOE used fewer points to develop a linear fit for the energy-saving lamp wattages.

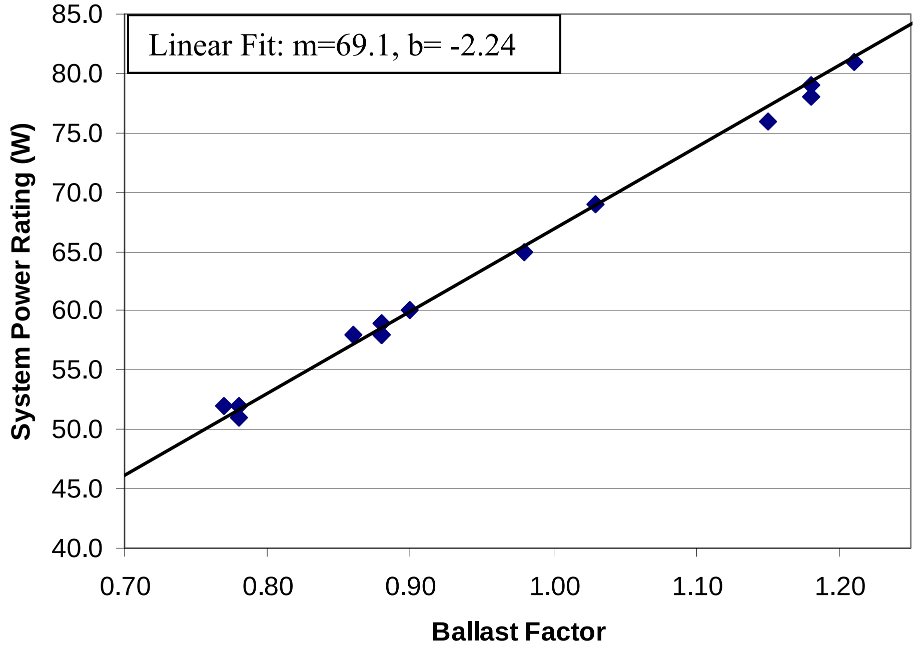

Figure 5.3.8 Two-Lamp 32W T8 120V Ballasts with THD <20 Percent, PF >0.95, and BEF 1.40-1.53

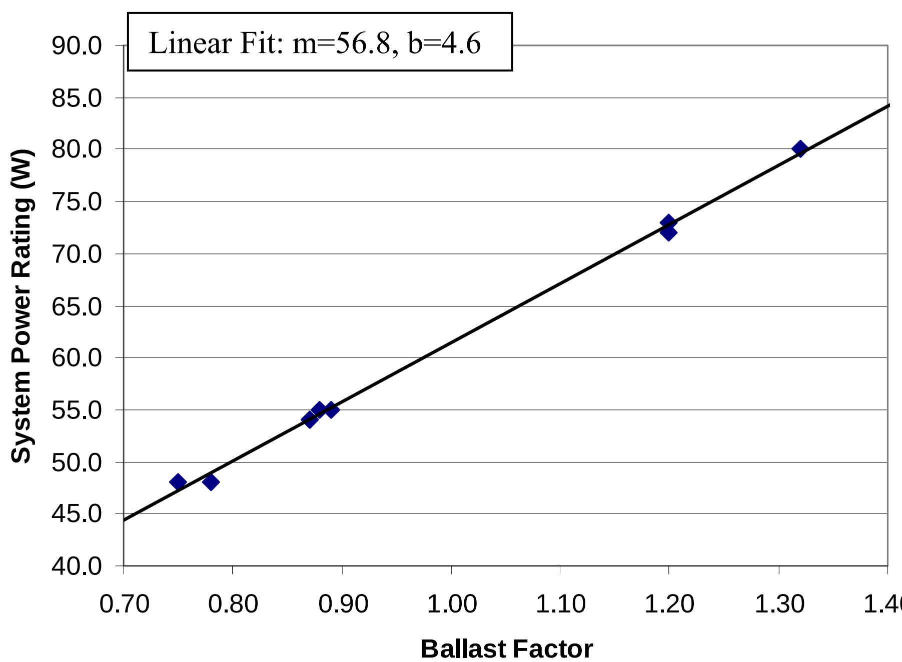

Figure 5.3.9 Two-Lamp 30W T8 120V Ballasts with THD <20 Percent, PF >0.95, and BEF 1.56-1.67

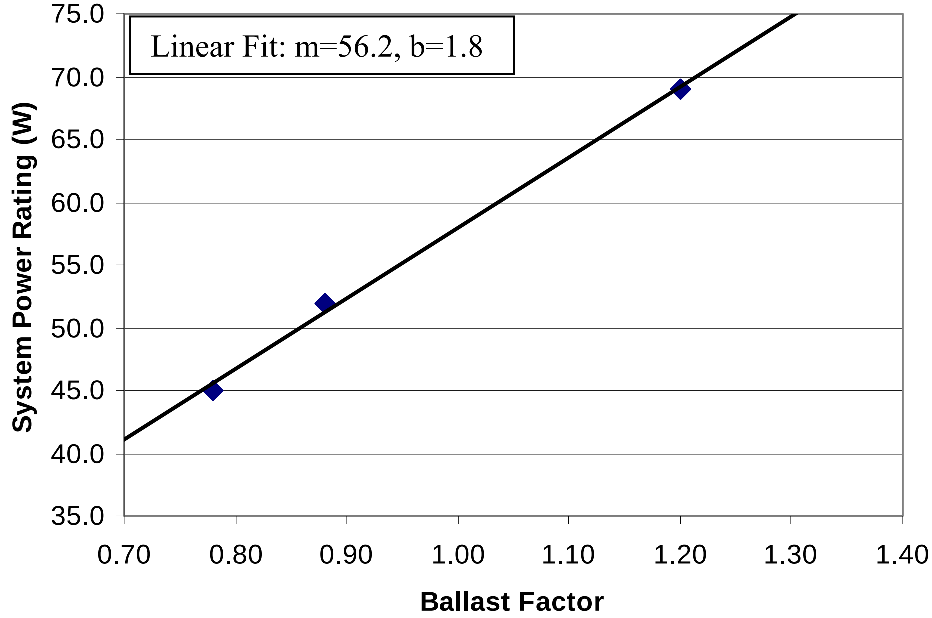

Figure 5.3.10 Two-Lamp 28W T8 120V Ballasts with THD <20 Percent, PF >0.98, and BEF 1.69-1.73

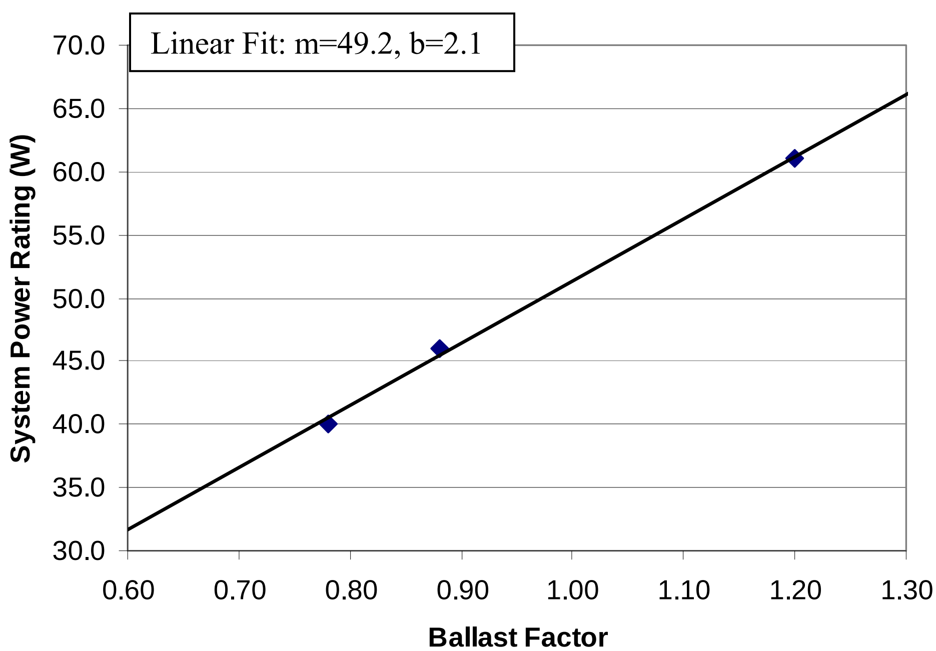

Figure 5.3.11 Two-Lamp 25W T8 120V Ballasts with THD <20 Percent, PF >0.98, and BEF 1.91-1.97

Figure 5.3.12 to Figure 5.3.15 show the linear fit and ballast characteristics DOE used to derive the system power rating for three-lamp, 4-foot T12 MBP lamps on electronic ballasts. Because manufacturer literature for these lamps is uncommon, DOE extrapolated linear fits from the two-lamp, 4-foot T12 based on the relative difference between the three-lamp and two-lamp 32W T8 slopes. To develop the y-intercept, DOE used a data point from manufacturer literature for three-lamp, 4-foot T12s with a common BEF.

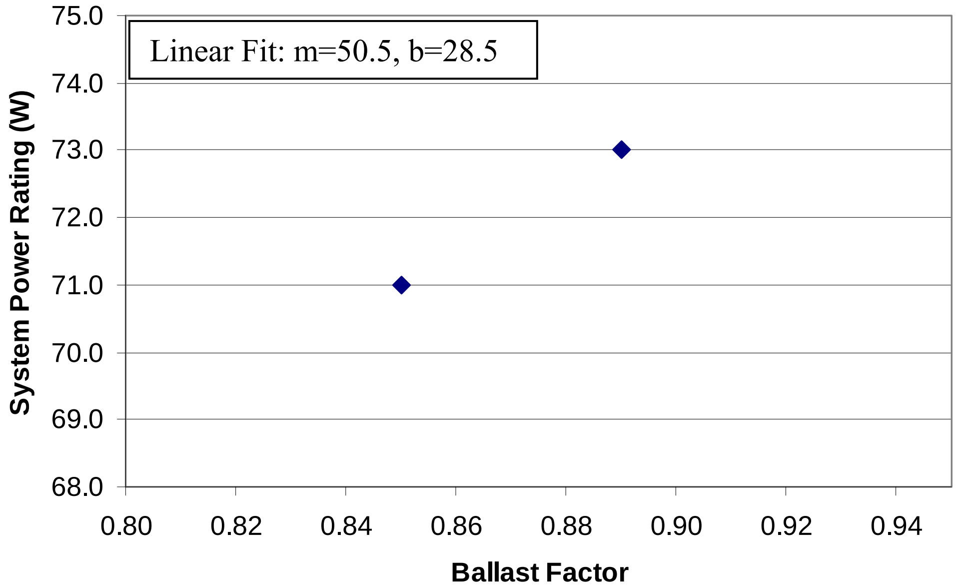

Figure 5.3.12 Two-Lamp 40W 120V Ballasts with <20 Percent THD, PF >0.95, and BEF 1.20-1.22 in the Commercial and Industrial Sectors

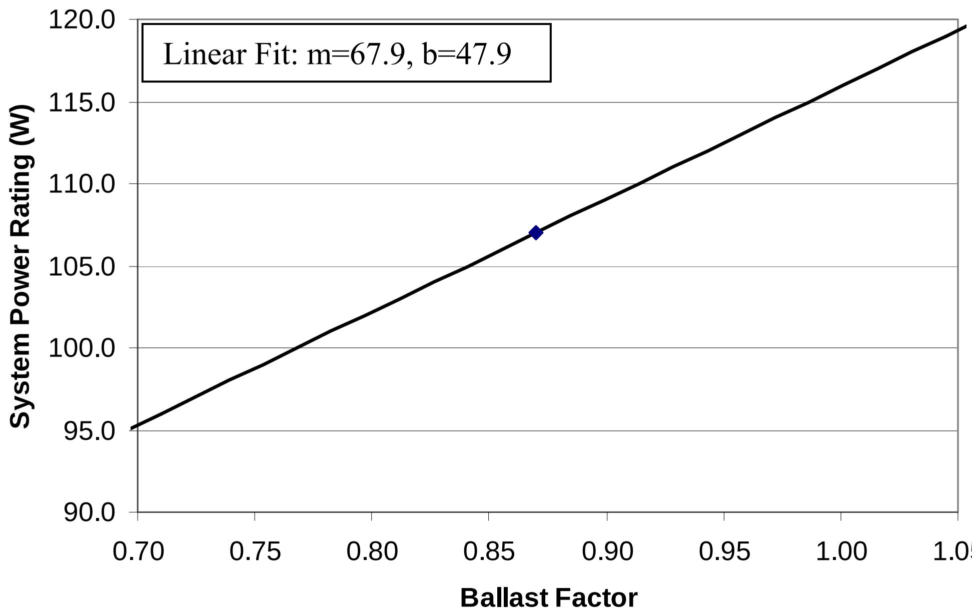

Figure 5.3.13 Three-Lamp 40W 120V Ballasts Linear Fit (Based on Slope Change from Two-Lamp to Three-Lamp Ballasts for 32W T8 Applied to T12 and Common T12 Electronic Ballast)

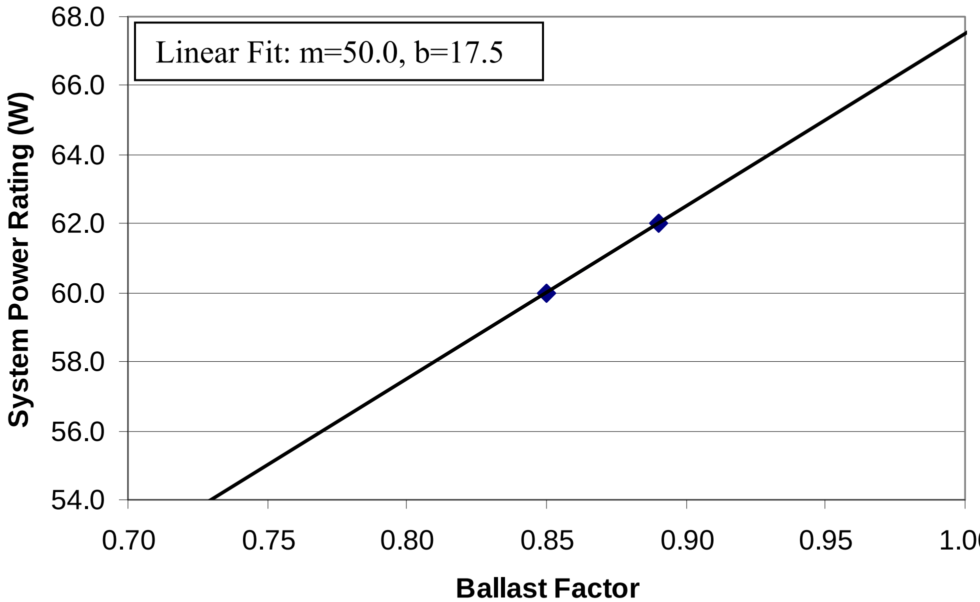

Figure 5.3.14 Two-Lamp 34W 120V Ballasts with <20 Percent THD, PF >0.95, and BEF 1.42-1.44 in the Commercial and Industrial Sectors

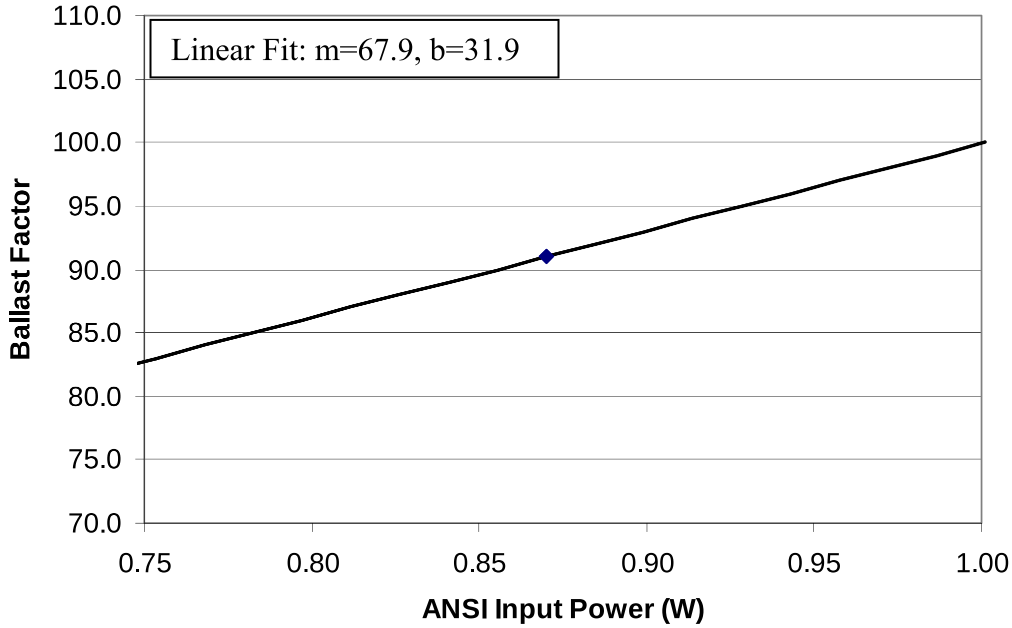

Figure 5.3.15 Three-Lamp 34W 120V Ballasts (Based on Slope Change from Two-Lamp to Three-Lamp Ballasts for T8 Applied to T12 and Common T12 Electronic Ballast)

Figure 5.3.16 and Figure 5.3.17 show the linear fit and ballast characteristics DOE used to derive the system power rating for two-lamp, 4-foot T12 MBP lamps on electronic ballasts in the residential sector. To develop the linear fit, DOE used parameters of two 40W T12 and 34WT12 residential electronic ballasts.

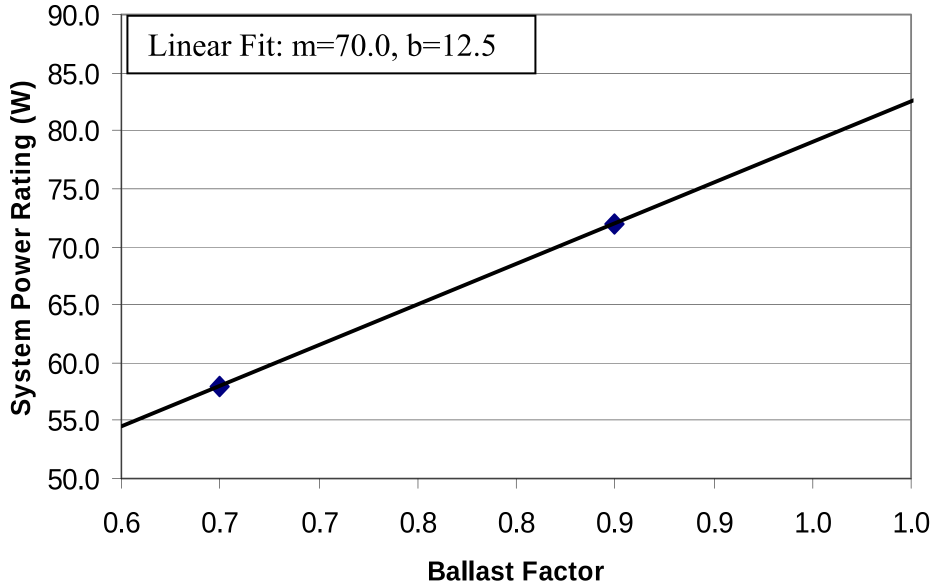

Figure 5.3.16 Two-Lamp 40W Ballasts with <40 Percent THD, PF >0.55, and BEF 1.12-1.18 in the Residential Sector

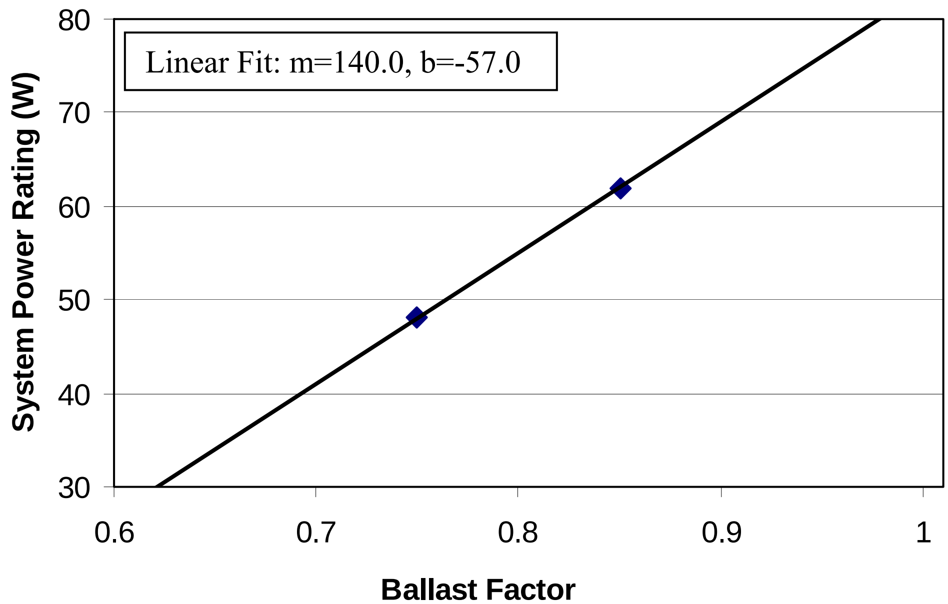

Figure 5.3.17 Two-Lamp 34W Ballasts with <50 Percent THD, PF >0.53, and BEF 1.37-1.56 in the Residential Sector

5.3.1.4 Results

As discussed above, DOE evaluated multiple baseline lamps for each product class to provide a comprehensive understanding of the consumer economics. For each baseline lamp, DOE considered only energy-saving options that result in approximately the same light output as the baseline lamp system. Energy savings could either be achieved through lamp or lamp and ballast replacements. Appendix 5A provides information on the additional lamp-and-ballast designs DOE uses in the NIA.

Table 5.3.6 presents the engineering characteristics of lamp replacement options for a baseline 40W 4-foot T12 MBP 4,100K lamp in the commercial and industrial sectors. Although a 34W T12 lamp is often considered a reduced-wattage replacement of the 40W T12 lamp, there are no lamp options that emit enough lumens to fall within 10 percent of the baseline system lumens. The highest efficacy 34W T12 lamp replacement is shown below in Table 5.3.6. The light output of this lamp-and-ballast design is 10.3 percent less than that of the baseline system. The same drop in lumen output is also exhibited by the 34W T12 lamp on an electronic ballast of the same BF.

Table 5.3.7 presents the engineering characteristics of lamp and ballast replacement options for a 40W 4-foot T12 MBP, 4,100K lamp in the commercial and industrial sectors. Note that at the higher ELs, DOE considered some T8 substitutes for the 40W T12 lamp. As discussed earlier, DOE adjusted the BF so that the combination of lamp and ballast maintains light output so that potential light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system. All standards-case lamps for lamp and ballast replacements are placed on electronic T12s or ballasts since ballast standards will be effective in 2010 for the commercial and industrial sectors.

Table 5.3.6 Lamp Replacement Engineering Analysis for a Three-Lamp 40W T12, 4,100K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor*	System Power Rating	System Initial Light Output	System Mean Light Output
		W	***W***	***lm/W***	***lm***	***lm***	***hr***			***W***	***lm***	***lm***
Baseline	T12	40	41.0	78.0	3,200	2,880	20,000	Magnetic	0.95	129.0	9,120	8,208
EL3	T12	34	34.0	91.2	3,100	2,790	24,000	Magnetic	0.88	108.0	8,184	7,366

*Note: This difference in BFs does not represent a ballast replacement. Instead, the BF of magnetic ballasts changes when a different wattage lamp is installed.

Table 5.3.7 Lamp and Ballast Replacement Engineering Analysis for a Three-Lamp 40W T12, 4,100K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*Lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	40	41.0	78.0	3,200	2,880	20,000	Magnetic	0.95	129.0	9,120	8,208
Baseline	T12	40	41.0	78.0	3,200	2,880	20,000	Electronic	0.88	107.7	8,448	7,603
EL1	T12	40	41.0	80.5	3,300	3,000	20,000	Electronic	0.88	107.7	8,712	7,920
EL1	T12	40	41.0	80.5	3,300	3,000	20,000	Electronic	0.87	107.0	8,613	7,830
EL1	T12	40	41.0	82.9	3,400	3,060	24,000	Electronic	0.87	107.0	8,874	7,987
Baseline/EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	1.18	113.3	9,912	8,921
EL2	T12	40	41.0	87.8	3,600	3,250	24,000	Electronic	0.87	107.0	9,396	8,483
EL3	T12	34	34.0	91.2	3,100	2,790	24,000	Electronic	0.88	91.7	8,184	7,366
EL3	T8	32	32.5	90.8	2,950	2,710	20,000	Electronic	1.00	97.4	8,850	8,130
EL4	T8	32	32.5	92.3	3,000	2,850	24,000	Electronic	0.88	86.8	7,920	7,524
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	1.00	90.3	8,550	8,040
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	1.18	87.7	8,762	8,319
EL5	T8	32	32.5	95.4	3,100	2,915	24,000	Electronic	0.88	86.8	8,184	7,696
EL5	T8	28	28.4	96.0	2,725	2,560	18,000	Electronic	1.00	84.6	8,175	7,680

Table 5.3.8 presents the engineering characteristics of lamp replacement options for a baseline 40W 4-foot T12 MBP, 4,100K lamp in the residential sector. The highest efficacy 34W T12 lamp replacement is shown below in Table 5.3.8. The mean light output of this lamp-and-ballast design is 5.3 percent less than that of the baseline system.

Table 5.3.9 presents the engineering characteristics of lamp and ballast replacement options for a 40W 4-foot T12 MBP, 4,100K lamp in the residential sector. Note that at the higher ELs, DOE considered some T8 substitutes for the 40W T12 lamp. As discussed earlier, DOE adjusted the BF so that the combination of lamp and ballast maintains light output so that potential light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system. There is one 34W T12 standards-case lamp at EL3 that is placed on a magnetic ballast. Magnetic ballasts will continue to be sold in the residential sector under current regulations so consumers have the option to purchase a magnetic ballast in the standards case if it is an energy-saving option. DOE understands that certain residential ballasts cannot operate reduced-wattage (e.g., 34W T12) lamps. However, because some residential ballasts can operate reduced-wattage lamps, DOE is considering these lamp-and-ballasts systems as an option for some consumers in the residential sector. Consumers can also purchase lower ballast factor ballasts in order to maintain an equivalent lumen package to the baseline 40W T12 magnetic system. However, DOE did not consider other lamps on magnetic ballasts apart from the 34W T12 standards-case lamp at EL3 shown in the table because the systems either do not save energy or are not within 10 percent lumen output of the baseline system. All other standards-case lamps for lamp and ballast replacements are placed on electronic ballasts.

Table 5.3.8 Lamp Replacement Engineering Analysis for a Two-Lamp 40W T12, 4,100K System in the Residential Sector

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor*	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	40	41	76.8	3,150	2,860	15,000	Magnetic	0.68	70.0	4,284	3,890
EL3	T12	34	34	91.2	3,100	2,790	24,000	Magnetic	0.66	60.0	4,092	3,683

*Note: This difference in BFs does not represent a ballast replacement. Instead, the BF of magnetic ballasts changes when a different wattage lamp is installed.

Table 5.3.9 Lamp and Ballast Replacement Engineering Analysis for a Two-Lamp 40W T12, 4,100K System in the Residential Sector

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	40	41.0	76.8	3,150	2,860	15,000	Magnetic	0.68	70.0	4,284	3,890
EL1	T12	40	41.0	80.5	3,300	3,000	20,000	Electronic	0.65	58.0	4,290	3,900
EL1	T12	34	34.0	82.4	2,800	2,460	20,000	Electronic	0.85	62.0	4,760	4,182
EL1	T12	40	41.0	82.9	3,400	3,060	24,000	Electronic	0.65	58.0	4,420	3,978
EL2	T12	34	34.0	85.3	2,900	2,610	20,000	Electronic	0.75	48.0	4,350	3,915
EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	0.78	51.6	4,368	3,931
Baseline/EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	0.88	58.6	4,928	4,435
EL2	T12	40	41.0	87.8	3,600	3,250	24,000	Electronic	0.65	58.0	4,680	4,225
EL3	T12	34	34.0	91.2	3,100	2,790	24,000	Magnetic	0.66	60.0	4,092	3,683
EL3	T12	34	34.0	91.2	3,100	2,790	24,000	Electronic	0.75	48.0	4,650	4,185
EL3	T8	32	32.5	90.8	2,950	2,710	20,000	Electronic	0.75	49.6	4,425	4,065
EL3	T8	32	32.5	90.8	2,950	2,710	20,000	Electronic	0.78	51.6	4,602	4,228

Table 5.3.9 Lamp and Ballast Replacement Engineering Analysis for a Two-Lamp 40W T12, 4,100K System in the Residential Sector (continued)

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
EL4	T8	32	32.5	92.3	3,000	2,850	24,000	Electronic	0.75	49.6	4,500	4,275
EL4	T8	32	32.5	92.3	3,000	2,850	24,000	Electronic	0.78	51.6	4,680	4,446
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	0.75	47.2	4,275	4,020
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	0.78	48.9	4,446	4,181
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	0.78	40.5	3,861	3,666
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	0.88	45.4	4,356	4,136
EL5	T8	32	32.5	95.4	3,100	2,915	24,000	Electronic	0.71	46.8	4,402	4,139
EL5	T8	32	32.5	95.4	3,100	2,915	24,000	Electronic	0.75	49.6	4,650	4,373
EL5	T8	28	28.4	96.0	2,725	2,560	18,000	Electronic	0.78	45.6	4,251	3,994

Table 5.3.10 presents the engineering analysis results for the replacement lamp-and-ballast combinations for the 34W 4-foot T12 MBP baseline lamp in the commercial and industrial sectors. DOE has not identified any lower-wattage direct lamp replacement designs that could operate on the same ballast and save energy. In this table, T8 lamp and ballast replacements are considered for the baseline lamp, and the BF is selected so that the new system's light output never drops below 10 percent of the baseline system.

Table 5.3.10 Lamp and Ballast Replacement Engineering Analysis for a Three-Lamp 34W T12, 4,100K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	34	34.0	77.9	2,650	2,300	20,000	Magnetic	0.88	108.0	6,996	6,072
Baseline	T12	34	34.0	77.9	2,650	2,300	20,000	Electronic	0.88	91.7	6,996	6,072
EL1	T12	34	34.0	82.4	2,800	2,460	20,000	Electronic	0.88	91.7	7,392	6,494
EL1	T12	34	34.0	82.4	2,800	2,460	20,000	Electronic	0.86	90.3	7,224	6,347
EL2	T12	34	34.0	85.3	2,900	2,610	20,000	Electronic	0.86	90.3	7,482	6,734
Baseline/EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	0.88	86.8	7,392	6,653
EL3	T8	32	32.5	90.8	2,950	2,710	20,000	Electronic	0.78	77.9	6,903	6,341
EL3	T12	34	34.0	91.2	3,100	2,790	24,000	Electronic	0.86	90.3	7,998	7,198
EL4	T8	32	32.5	92.3	3,000	2,850	24,000	Electronic	0.75	75.3	6,750	6,413
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	0.78	72.2	6,669	6,271
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	0.88	66.5	6,534	6,204
EL5	T8	32	32.5	95.4	3,100	2,915	24,000	Electronic	0.71	71.7	6,603	6,209
EL5	T8	28	28.4	96.0	2,725	2,560	18,000	Electronic	0.78	67.5	6,377	5,990

Table 5.3.11 presents the engineering analysis results for the 32W 4-foot T8 MBP baseline lamp replacement in the commercial and industrial sectors. As shown below in Table 5.3.11, there are no lamp replacement options at EL3 because the system lumens of reduced wattage lamp replacement options below this EL are not maintained.

Table 5.3.12 presents the engineering analysis results for the replacement lamp and ballast combinations for the 32W 4-foot T8 MBP baseline lamp in the commercial and industrial sectors. For lamp-and-ballast replacement combinations, the BF is selected so that the new system's light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system.

Table 5.3.11 Lamp Replacement Engineering Analysis for a Three-Lamp 32W T8, 4,100K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*Lm*	*hr*			*W*	*lm*	*lm*
Baseline/ EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	0.88	86.8	7,392	6,653
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	0.88	80.4	7,524	7,075
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	0.88	66.5	6,534	6,204
EL5	T8	28	28.4	96.0	2,725	2,560	18,000	Electronic	0.88	75.3	7,194	6,758

Table 5.3.12 Lamp and Ballast Replacement Engineering Analysis for a Three-Lamp 32W T8, 4,100K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline/ EL2	T8	32	32.5	86.2	2,800	2,520	20,000	Electronic	0.88	86.8	7,392	6,653
EL3	T8	32	32.5	90.8	2,950	2,710	20,000	Electronic	0.78	77.9	6,903	6,341
EL4	T8	32	32.5	92.3	3,000	2,850	24,000	Electronic	0.75	75.3	6,750	6,413
EL4	T8	30	30.4	93.8	2,850	2,680	20,000	Electronic	0.78	72.2	6,669	6,271
EL4	T8	25	26.6	93.0	2,475	2,350	30,000	Electronic	0.88	66.5	6,534	6,204
EL5	T8	32	32.5	95.4	3,100	2,915	24,000	Electronic	0.75	75.3	6,975	6,559
EL5	T8	28	28.4	96.0	2,725	2,560	18,000	Electronic	0.88	75.3	7,194	6,758

5.3.2 Eight-foot SP Slimline GSFL With CCTs ≤ 4,500K

5.3.2.1 Baseline Models

The 8-foot SP slimline lamps with CCTs less than or equal to 4,500K are commonly manufactured in both T8 and T12 diameters. As discussed in chapter 3, the T12 diameter represents approximately 85 percent of all 8-foot SP slimline lamp shipments. However, DOE projects that by 2011, T8s will account for 26 percent of all 8-foot SP slimline lamp shipments. Therefore, DOE selected its baseline models for this product class from both the T12 and T8 diameter. The two most popular wattages associated with the 8-foot T12 SP slimline lamp type are the 60W and 75W. For the 60W lamp, the cool white halophosphor is the most popular. Therefore, DOE selected this as the baseline. The most common 75W T12 lamp purchased uses a rare earth 700 series phosphor. For T8 lamps, the most popular wattage is 59W. The most common lamp purchased at this wattage uses a rare earth 700 series phosphor. As with the 4-foot MBP, DOE selects a CCT of 4,100K because it is the most common CCT for this lamp type.

When selecting baseline lamps, DOE found small variances in the reported lumen outputs (and therefore efficacies). DOE selected the least efficacious baseline lamps to ensure that all the major manufacturers have a product available at the baseline.

DOE's review of product literature for 8-foot T12 SP slimline lamps indicated that a 12,000-hour lifetime is typical, although this is shorter than the lifetime of the 4-foot MBP. T12 lamps with a 15,000-hour lifetime for a 3-hour cycle are marketed as extended performance products. Therefore, DOE used a lifetime of 12,000 hours for a 3-hour cycle for the baseline unit of analysis for T12 lamps.

DOE's review of product literature for 8-foot T8 SP slimline lamps indicated that 15,000 hours is a typical lifetime. T8 lamps with a 24,000-hour lifetime for a 3-hour cycle are marketed as extended performance products. Therefore, DOE used a lifetime of 15,000 hours for a 3-hour cycle for the baseline unit of analysis for T8 lamps.

The most common ballast for 8-foot T12 SP slimline lamps is a two-lamp, instant-start, 120V, magnetic ballast. This ballast typically has a 0.94 BF when a 75W 8-foot T12 SP slimline lamp is installed and a 0.88 BF when a 60W 8-foot T12 SP slimline lamp is installed. The most common ballast used for 8-foot T8 SP slimline lamps is a two-lamp, instant-start, 120V, electronic ballast with a 0.88 BF. The 75W T12 baseline lamp-and-ballast combination creates a lumen package of approximately 11,100 mean lumens (and 12,070 initial lumens). The 60W T12 baseline lamp-and-ballast combination creates a lumen package of approximately 8,210 mean lumens (and 9,330 initial lumens). The 59W T8 baseline lamp-and-ballast combination creates a lumen package of almost 9,030 mean lumens (and more than 10,030 initial lumens).

Table 5.3.13 Baseline Units of Analysis for 8-Foot SP Slimline Lamps

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*lm*	*hr*
T12	75	70	4,100	85.6	6,420	5,906	12,000
T12	60	62	4,100	87.6	5,300	4,664	12,000
T8	59	70	4,100	94.8	5,700	5,130	15,000

* Rated efficacy is based on the rated wattage of the lamps, which is 75W and 60.5W for T12 lamps and 60.1W for T8 lamps.

5.3.2.2 Efficacy Levels

As with the previous product class, DOE established ELs for design options that are consistent across the three baseline 8-foot SP slimline lamps. However, not every EL affects every baseline lamp. Because the three baseline lamps have different efficacy values, the first EL only affects the 75W lamp. However, for EL4 and above, the requirements affect all three baseline lamps.

In selecting ELs, DOE considered two different paths to energy savings. One involves reduced-wattage replacement lamps, which could be installed in a socket and operate on the existing ballast. These lower-wattage replacement lamps have a higher efficacy and therefore produce about the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system). The other path to energy savings involves lamps that have the same or lower wattage in comparison with the baseline lamp, but operate on a new ballast with a different BF so the system energy is lower. DOE selected the BF with the more-efficacious lamp to produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system).

The following discussion identifies the steps and technologies associated with each EL DOE considered. As discussed in the screening analysis (chapter 4), DOE used design options with highly emissive electrode coatings, higher efficacy lamp fill gas composition, higher efficacy phosphors, glass coatings, or higher efficacy lamp diameter to achieve a higher efficacy level. Because high-efficacy phosphors and lamp diameter are common methods to achieve higher efficacies, DOE identified the diameter and phosphor associated with each EL based on an analysis of catalog data:

EL1. This level affects just the 75W T12 baseline lamp, moving this technology from a 700 series rare earth phosphor to an 800 series rare earth phosphor. This level does not affect the 60W T12 baseline lamp since it is above the baseline efficacy.

EL2. This level represents the highest efficacy for the T12 lamp at 75W. At that efficacy, the lamp incorporates premium 800 series rare earth phosphor. For the 60W lamp, this level requires a 700 series rare earth phosphor.

EL3. DOE selected this level because it represents the only viable 60W replacement that would operate on a 75W ballast with the same CCT as the baseline lamp (4,100K). No lamps at

75W can achieve this EL. For the 60W lamp, this level requires an improved 700 series rare earth phosphor.

EL4. At this level, ballast changes may be required for those users who need a lamp with a CCT of 4,100K, since only 4,100K T8 lamps are compliant. T8 lamps transition from a 700 series rare earth phosphor at EL3 to an 800 series rare earth phosphor.

EL5. At this level, ballast changes are required for T8 technology. Also, at this level lamps use the premium 800 series rare earth phosphor. This level represents the highest efficacy level available, or max-tech for 8-foot SP slimline lamps.

Figure 5.3.18 illustrates five initial ELs based on catalog values of commercially-available fluorescent lamps on a plot of selected 8-foot SP slimline lamps analyzed by DOE to determine efficacy level requirements. A line at 80.0 lm/W denotes the existing energy conservation standard (from EPACT). Square boxes and labels identify the two baseline lamps. The plot shows the replacement lamps DOE considered. Some are the same wattage, but have a higher efficacy; others have lower wattage and higher efficacy so that the lamp-and-ballast system maintains light output at no less than 10 percent of the baseline lamp-and-ballast system.

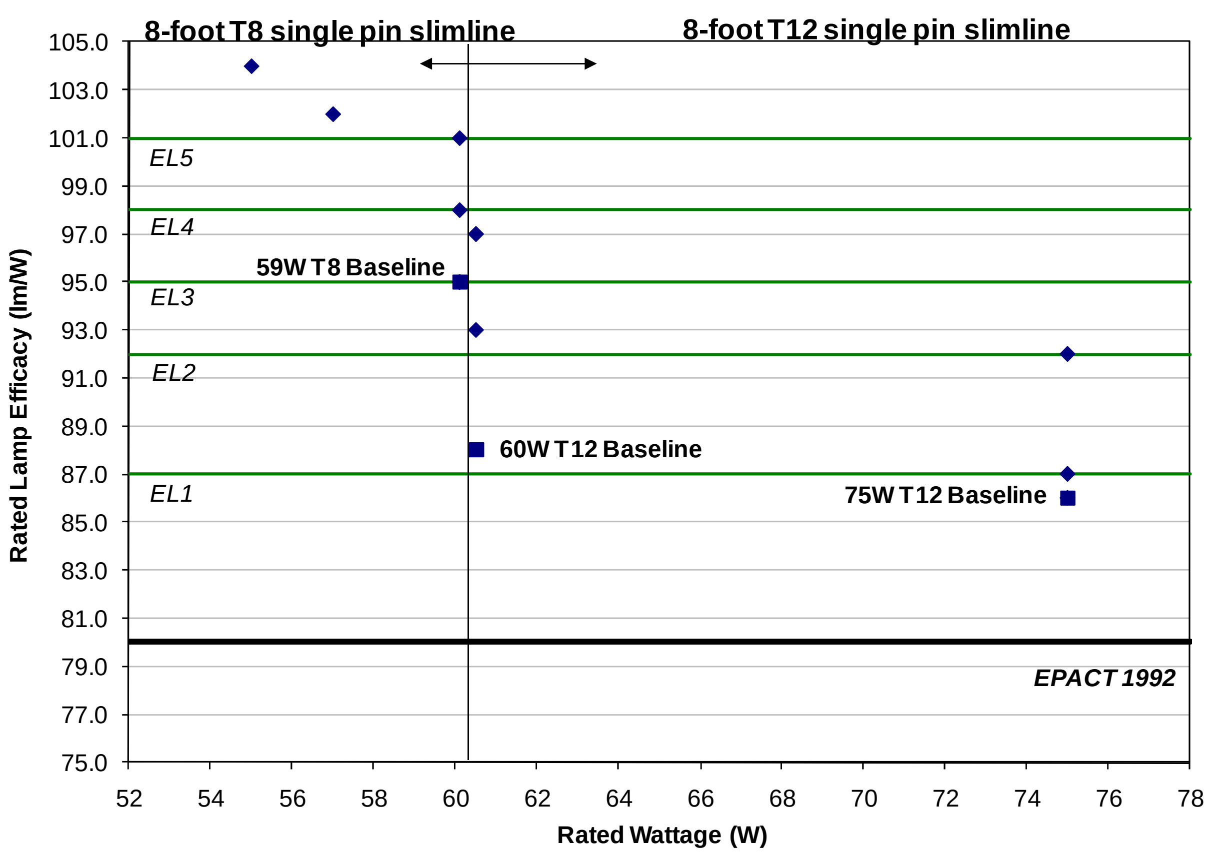

Figure 5.3.18 Initial Efficacy Levels for 8-Foot SP Slimline Lamps With CCTs ≤ 4,500K

Table 5.3.14 provides detailed information on the 8-foot SP slimline lamp designs used in the engineering analysis and subsequent analyses.

Table 5.3.14 8-Foot SP Slimline Lamp Designs

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	CRI
		W	*W*	*lm/W*	*lm*	*lm*	*hr*	
Baseline/0	T12	75	75.0	85.6	6,420	5,906	12,000	70
1	T12	75	75.0	87.3	6,550	6,157	12,000	80
Baseline/1	T12	60	60.5	87.6	5,300	4,664	12,000	62
2	T12	75	75.0	92.0	6,900	6,370	15,000	80
2	T12	60	60.5	92.6	5,600	5,152	12,000	70
Baseline/3	T8	59	60.1	94.8	5,700	5,130	15,000	75
3	T12	60	60.5	97.5	5,900	5,480	15,000	73
4	T8	59	60.1	98.2	5,900	5,428	15,000	82
5	T8	59	60.1	101.5	6,100	5,795	18,000	85
5	T8	57	57.0	101.8	5,800	5,450	24,000	81
5	T8	55	55.0	103.6	5,700	5,415	18,000	82

As seen above, DOE used commercially-available lamps and their associated rated efficacies (rated initial lumen output divided by the ANSI rated wattage) to determine the design options required to meet each efficacy level. However, to establish the minimum efficacy requirements for each efficacy level, DOE coupled catalog data on commercially-available lamps with data submitted to DOE by manufacturers for the purpose of compliance with existing energy conservation standards for general service fluorescent lamps. DOE's use of compliance report data is discussed in further detail in section 5.3.1.2. Figure 5.3.19 below shows all compliance report data for 8-foot SP slimline lamps with CCTs less than or equal to 4,500K.

As discussed in section 5.3.1.2, DOE considered only recent compliance report data in establishing minimum efficacy requirements. Figure 5.3.19 depicts compliance report data from the years 2007 and 2008 in gray circles. For 8-foot SP slimline lamps, DOE found that not enough data existed from compliance reports submitted in 2007 and 2008 to establish several of efficacy levels with reasonable certainty. Therefore, DOE adjusted these levels to reflect the minimum efficacy requirements recommended by NEMA in their written comments. Table 5.3.15 summarizes the resulting efficacy requirements for 8-foot SP slimline lamps with CCTs less than or equal to 4,500K, after accounting for compliance data.

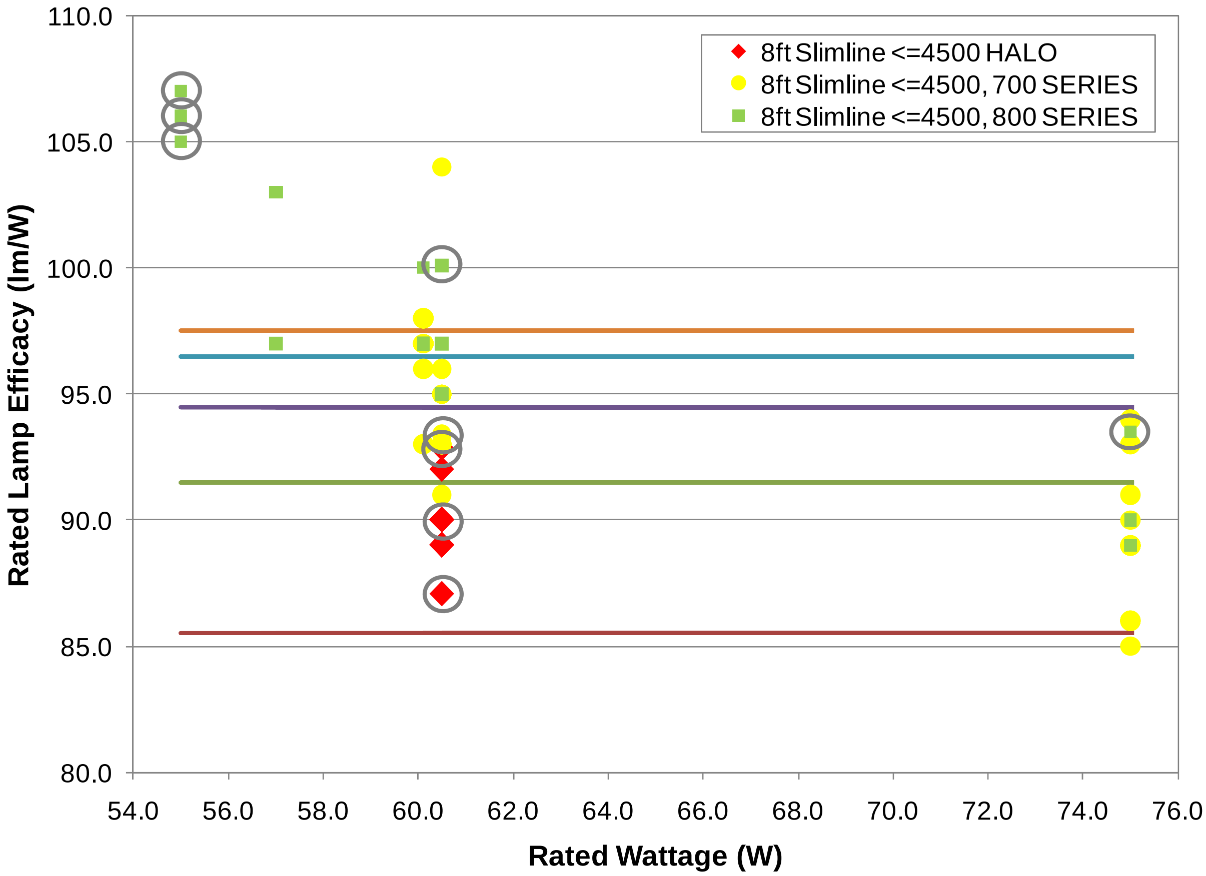

Figure 5.3.19 All Compliance Report Data for 8-Foot SP Slimline Lamps with CCTs ≤ 4,500K

Table 5.3.15. Summary of the ELs for 8-Foot SP Slimline Lamps With CCTs ≤ 4,500K

Efficacy Level	Efficacy Requirement *lm/W*
EL1	86
EL2	92
EL3	95
EL4	97
EL5	98

Section 5.3.2.4 presents additional information about the lamp and ballast systems DOE develops in the engineering analysis.

5.3.2.3 System Power Rating

For each lamp wattage and ballast type, DOE linearly fit the system power rating of a lamp on several different ballasts with varying BFs.

Figure 5.3.20 to Figure 5.3.21 show the linear fit and ballast characteristics DOE used to derive the system power rating for 2-lamp, 8-foot T12 SP slimline lamps on electronic ballasts. The fit follows the form of Eq. 5.1 where $SPR = m * BF + b$. The ballasts DOE chose for these calculations typically have a THD less than 20 percent, PF greater than 0.95, and typical BEF. Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages.

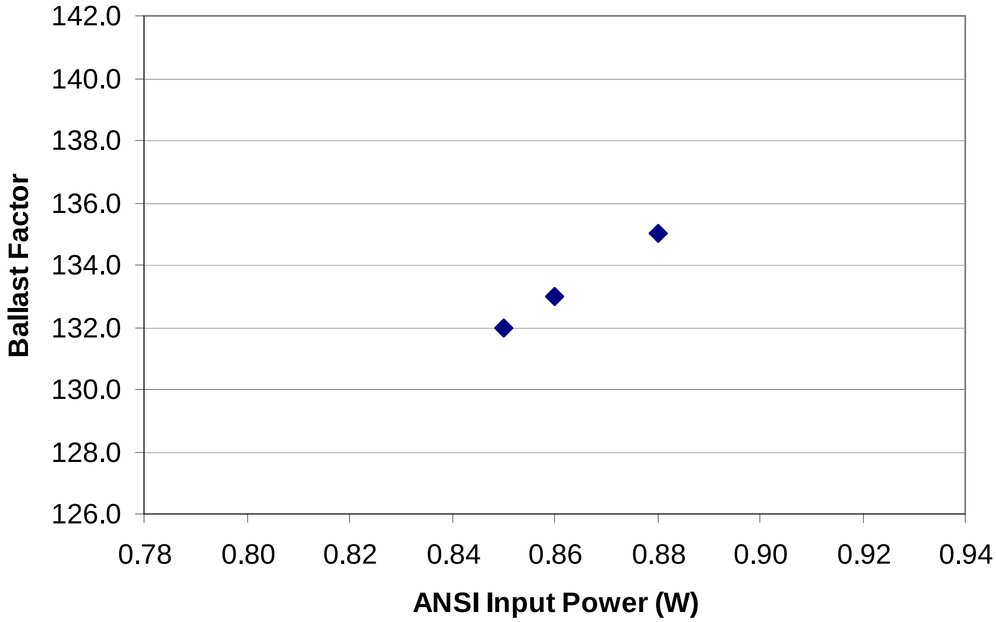

Figure 5.3.20 Two-Lamp 75W T12 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.64-0.66; Linear Fit: m=100.0, b=47.0

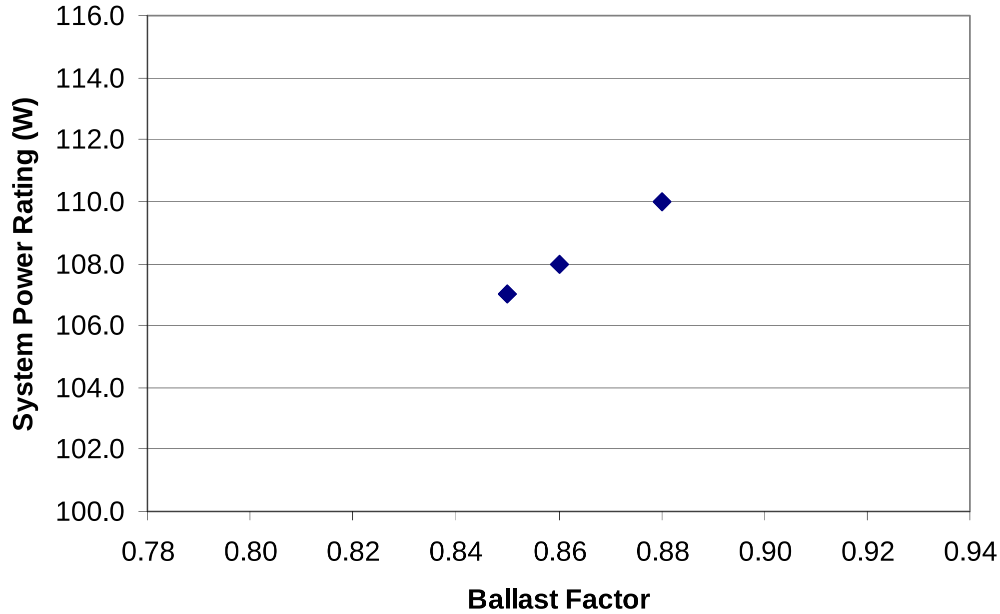

Figure 5.3.21 Two-Lamp 60W T12 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.79-0.80; Linear Fit: m=100.0, b=22.0

Figure 5.3.22 to Figure 5.3.24 show the linear fit and ballast characteristics DOE used to derive the system power rating for two-lamp, 8-foot T8 SP slimline lamps on electronic ballasts. The ballasts DOE used for these calculations typically have a THD less than 20 percent, PF greater than 0.95, and typical BEF. Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages. Also, because there is less manufacturer literature on system power ratings of ballasts with lower wattage lamps, DOE used fewer points to develop a linear fit at the energy saving lamp wattages.

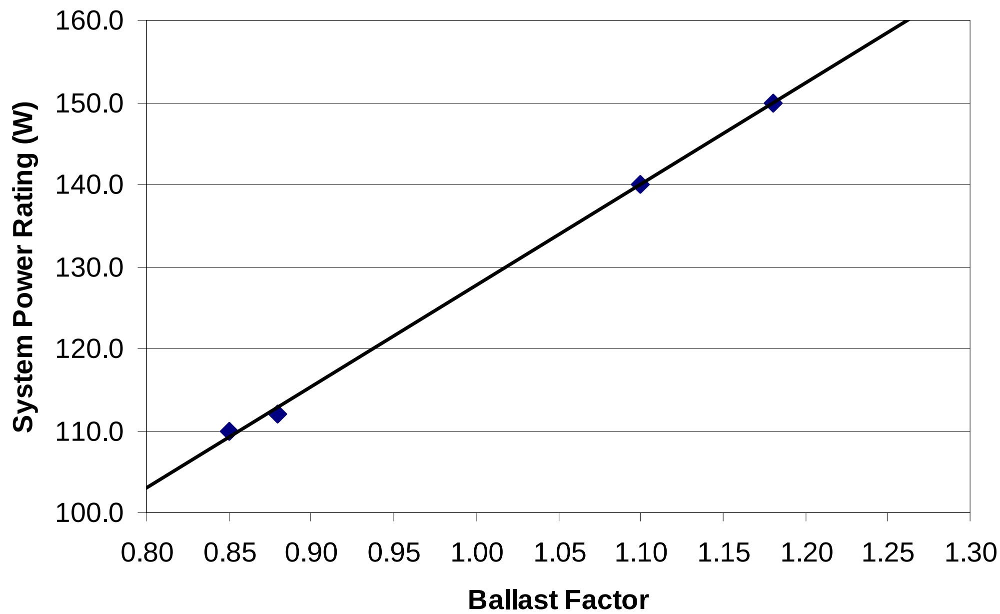

Figure 5.3.22 Two-Lamp 59W T8 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.77-0.79; Linear Fit: m=123.7, b=4.0

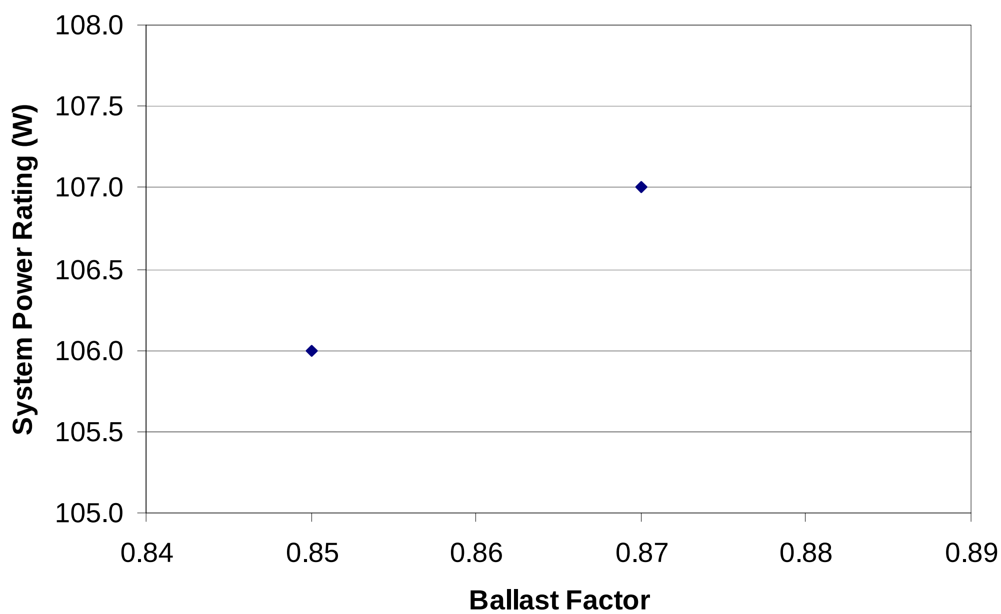

Figure 5.3.23 Two-Lamp 57W T8 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.80-0.81; Linear Fit: m=50.0, b=63.5

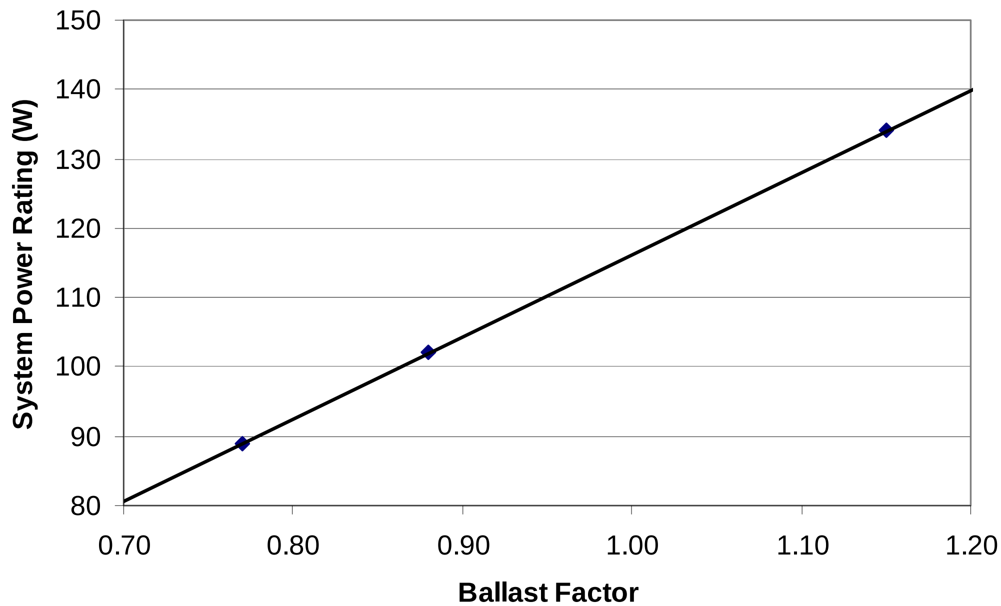

Figure 5.3.24 Two-Lamp 55W T8 120V Ballasts with THD <10 percent, and BEF 0.86; Linear Fit: m=118.4, b=-2.2

5.3.2.4 Results

DOE evaluated three baseline lamps for the 8-foot SP slimline product class: a 75W T12 lamp, a 60W T12 lamp, and a 59W T8 lamp. For each baseline lamp, DOE considered both direct-replacement lamps that operate on the existing ballast and lamp-and-ballast replacement designs that result in approximately the same light output as the baseline lamp. As discussed earlier, DOE adjusted the BF so that the light output of the lamp-and-ballast design system never drops below 10 percent of the baseline system.

Table 5.3.16 and Table 5.3.17 present the engineering characteristics of the lamp replacement and lamp-and-ballast replacement designs for the baseline 75W 8-foot T12 SP slimline, 4,100K lamp system. Although a 60W T12 lamp is often considered a reduced-wattage replacement of the 75W T12 lamp, there are no lamp options with a CCT of 4,100K that emit enough lumens to fall within 10 percent of the baseline system mean lumens. The highest-efficacy 4,100K, 60W T12 lamp replacement is shown below in Table 5.3.16. The light output of this lamp-and-ballast design is 13 percent less than that of the baseline system. DOE also included lamp-and-ballast replacement options for a 75W T12, 4,100K lamp. Note that at the higher ELs, DOE considers some T8 substitutes for the 75W T12 lamp.

Table 5.3.16 Lamp Replacement Engineering Analysis for a 75W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor*	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	75	75.0	85.6	6,420	5,906	12,000	Magnetic	0.94	158.0	12,070	11,103
EL3	T12	60	60.5	97.5	5,900	5,480	15,000	Magnetic	0.88	126.0	10,384	9,645

*Note: This difference in BFs does not represent a ballast replacement. Rather, the BF of magnetic ballasts changes when the lower wattage lamp is installed.

Table 5.3.17 Lamp-and-Ballast Replacement Engineering Analysis for a 75W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	75	75.0	85.6	6,420	5,906	12,000	Magnetic	0.94	158.0	12,070	11,103
Baseline	T12	75	75.0	85.6	6,420	5,906	12,000	Electronic	0.88	135.0	11,299	10,395
EL1	T12	75	75.0	87.3	6,550	6,157	12,000	Electronic	0.85	132.0	11,135	10,467
EL2	T12	75	75.0	92.0	6,900	6,370	15,000	Electronic	0.85	132.0	11,730	10,829
Baseline/EL3	T8	59	60.1	94.8	5,700	5,130	15,000	Electronic	1.18	149.9	13,452	12,107
EL5	T8	59	60.1	101.5	6,100	5,795	18,000	Electronic	0.88	112.8	10,736	10,119

Table 5.3.18 presents the engineering analysis results for the replacement lamp-and-ballast combinations for the 60W 8-foot T12 SP slimline baseline lamp. DOE did not identify any lower-wattage direct lamp replacement designs that could operate on the same ballast as a 60W T12 and save energy. In this table, DOE considered T8 lamp-and-ballast replacements for the baseline lamp, and selected the BF so that the light output of the new system never drops below 10 percent of the baseline system.

Table 5.3.18 Lamp-and-Ballast Replacement Engineering Analysis for a 60W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	W	*lm*/W	*lm*	*lm*	*hr*			*W*	lm	lm
Baseline/EL1	T12	60	60.5	87.6	5,300	4,664	12,000	Magnetic	0.88	126.0	9,328	8,209
Baseline/EL1	T12	60	60.5	87.6	5,300	4,664	12,000	Electronic	0.88	110.0	9,328	8,209
EL2	T12	60	60.5	92.6	5,600	5,152	12,000	Electronic	0.85	107.0	9,520	8,758
EL3	T12	60	60.5	97.5	5,900	5,480	15,000	Electronic	0.85	107.0	10,030	9,316
Baseline/EL3	T8	59	60.1	94.8	5,700	5,130	15,000	Electronic	0.88	112.8	10,032	9,029
EL4	T8	59	60.1	98.2	5,900	5,428	15,000	Electronic	0.78	100.4	9,204	8,468
EL5	T8	57	57.0	101.8	5,800	5,450	24,000	Electronic	0.78	102.5	9,048	8,502
EL5	T8	59	60.1	101.5	6,100	5,795	18,000	Electronic	0.78	100.4	9,516	9,040

Table 5.3.19 and Table 5.3.20 present the engineering analysis results for the lamp replacement and lamp-and-ballast replacement options for the 59W 8-foot T8 SP slimline baseline lamp. In Table 5.3.19, no lamp replacement options at EL4 are shown because the system lumens of reduced-wattage lamp replacement options below this EL are more than 10 percent less than that of the baseline system. For lamp-and-ballast replacement combinations, DOE selected the BF so that the light output of the new system is equal to, greater than, or no more than 10 percent less than the light output of the baseline system.

Table 5.3.19 Lamp Replacement Engineering Analysis for a Two-Lamp, 59W, T8, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline/EL3	T8	59	60.1	94.8	5,700	5,130	15,000	Electronic	0.88	112.8	10,032	9,029
EL5	T8	57	57.0	101.8	5,800	5,450	24,000	Electronic	0.88	107.5	10,208	9,592
EL5	T8	55	55.0	103.6	5,700	5,415	18,000	Electronic	0.88	102.0	10,032	9,530

Table 5.3.20 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp, 59W, T8, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage*	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline/EL3	T8	59	60.1	94.8	5,700	5,130	15,000	Electronic	0.88	112.8	10,032	9,029
EL4	T8	59	60.1	98.2	5,900	5,428	15,000	Electronic	0.85	109.1	10,030	9,228
EL5	T8	57	57.0	101.8	5,800	5,450	24,000	Electronic	0.85	106.0	9,860	9,265
EL5	T8	59	60.1	101.5	6,100	5,795	18,000	Electronic	0.78	100.4	9,516	9,040
EL5	T8	55	55.0	103.6	5,700	5,415	18,000	Electronic	0.88	102.0	10,032	9,530

5.3.3 Eight-Foot RDC HO GSFL With CCTs ≤ 4,500K

5.3.3.1 Baseline Models

The 8-foot RDC HO lamps with CCTs ≤ 4,500K are manufactured in both T8 and T12 diameters. As discussed in chapter 3, the T12 diameter represents the majority of 8-foot RDC HO lamp shipments today and will continue to represent the majority in 2011. Therefore, DOE selected its baseline models for this product class from the T12 diameter, which represents the most popular lamp type.

The two most popular wattages associated with the 8-foot T12 RDC HO lamp type are the 95W and 110W. For the 95W lamp, the cool white halophosphor lamp is the most popular. Therefore, DOE selected this lamp as the baseline 95W lamp. For the 110W T12 lamp, the most common lamp purchased uses a rare earth 700 series phosphor. The efficacy of both baseline lamps is approximately 2 lm/W greater than the EPACT 1992 standard level of 80 lm/W, but no other lamps met the EPACT 1992 CRI requirements, which are lower than either baseline lamp. As with the baseline fluorescent lamps in other covered product classes, DOE selected a CCT of 4,100K because it is the most common CCT for this lamp type.

The typical operating lifetime for these lamps is the same as that of the 8-foot SP slimline T12 lamps. The lamp lifetime is typically 12,000 hours. Lamps with a 15,000-hour lifetime on a 3-hour cycle are marketed as extended performance products. Therefore, DOE used a lifetime of 12,000 hours for a 3-hour cycle for the baseline unit of analysis for 8-foot RDC HO lamps.

DOE used a rapid-start, 120V, magnetic ballast for the baseline 8-foot T12 RDC systems as current regulations do not ban magnetic cold-temperature ballasts, which operate a large portion of the installed base of 8-foot T12 RDC HO lamps. The ballast has a ballast factor of 0.95 when used with 110W lamps and a ballast factor of 0.91 when used with 95W lamps. Together, the 110W T12 baseline lamp-and-ballast combination creates a lumen package of approximately 15,480 mean lumens (and 17,200 initial lumens), while the 95W T12 baseline lamp-and-ballast combination creates a lumen package of approximately 12,650 mean lumens (and 14,560 initial lumens).

Table 5.3.21 Baseline Units of Analysis for 8-Foot RDC High-Output Lamps

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*lm*	*hr*
T12	110	70	4,100	80.1	9,050	8,145	12,000
T12	95	62	4,100	82.5	8,000	6,950	12,000

* Rated efficacy is based on the rated wattage of the lamps, which is 97W for the 95W T12 and 113W for the 110W T12.

5.3.3.2 Efficacy Levels

As with the previous product class, DOE established ELs around design options that are consistent across the two baseline lamps. In selecting ELs, DOE considered two different paths to energy savings. The first involves reduced-wattage replacement lamps that could be installed in a socket and operate on the existing ballast. These lower-wattage replacement lamps have a higher efficacy and therefore produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system). The other path to energy savings involves lamps that have the same rated wattage as the baseline lamp, but operate on a new ballast with a different BF, so system energy is lower. DOE selected the BF with the more efficacious lamp to produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system).

The following discussion identifies the steps and technologies associated with each EL DOE considered. As discussed in the screening analysis (chapter 4), DOE used design options with highly-emissive electrode coatings, higher-efficacy lamp fill gas composition, higher-efficacy phosphors, glass coatings, or higher-efficacy lamp diameter to achieve higher efficacy levels. Because high-efficacy phosphors and lamp diameter are common methods to achieve higher efficacies, DOE identified the diameter and phosphor associated with each EL:

EL1. This level requires a 110W T12 lamp to use 800 series rare earth phosphor.

EL2. This level cannot be achieved by any 110W T12 lamp. This level also requires the 95W T12 lamp to move to a rare earth 700 series phosphor.

EL3. This level cannot be achieved by any 110W T12 lamp. For a 95W T12 lamp, this level requires a shift to the 800 series rare earth phosphor.

EL4. This level eliminates all T12 lamps; only T8 lamps comply which requires a ballast change. This standard level can be achieved with a 700 series rare earth phosphor in the T8 lamp.

EL5. This level also eliminates all T12 lamps; only T8 lamps comply, which requires a ballast change. This standard level represents the highest efficacy level available, or max-tech for 8-foot RDC HO lamps. This level can only be achieved with an 800 series rare earth phosphor in the T8 lamp.

Figure 5.3.20 illustrates five initial ELs that DOE selected to analyze based on catalog values of commercially-available fluorescent lamps on a plot of selected fluorescent lamps. A line at 80.0 lm/W denotes the existing energy conservation standard (from EPACT 1992). Square boxes and labels identify the two baseline lamps. The plot also shows the high-efficacy replacement lamps DOE considered for each baseline lamp. Some are at the same wattage, but have a higher efficacy; others have a combination of lower wattage and higher efficacy so that the light output never drops below 10 percent of the baseline system.

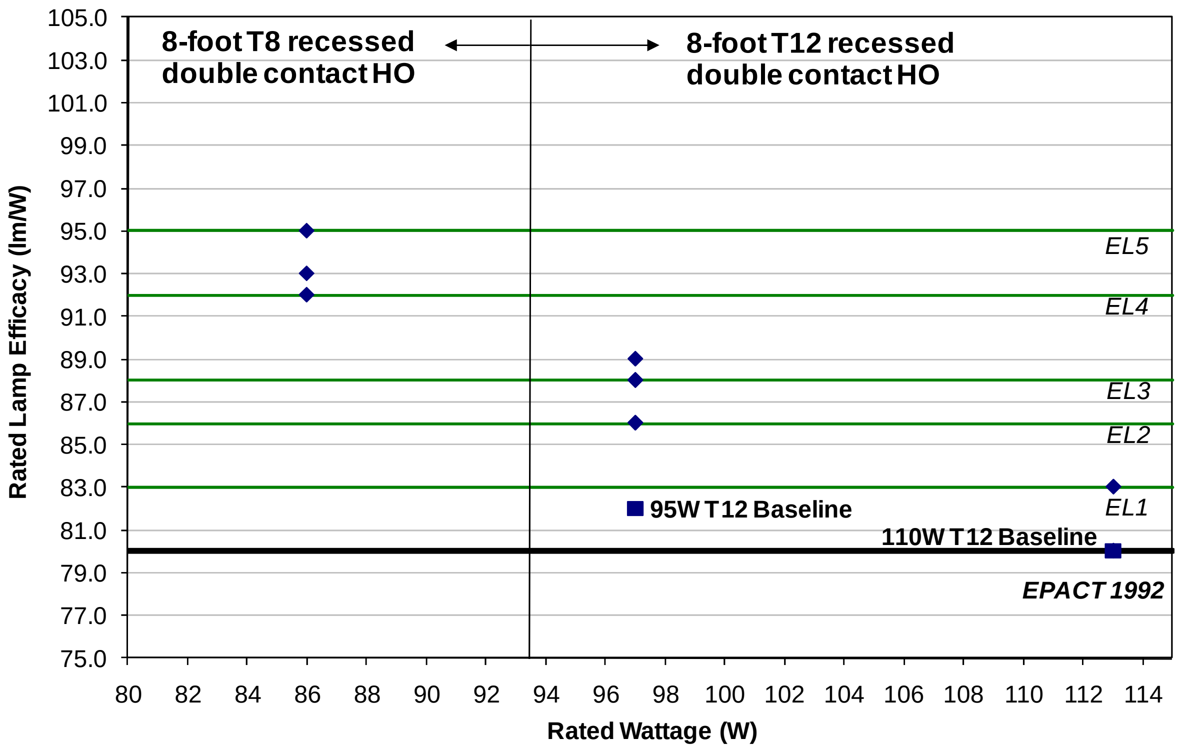

Figure 5.3.25 Initial Efficacy Levels for 8-Foot RDC HO Lamps With CCTs ≤ 4,500K

Table 5.3.22 provides detailed information on the 8-foot RDC HO lamp designs used in the engineering analysis and subsequent analyses.

Table 5.3.22 8-Foot RDC HO Lamp Designs

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	CRI
		W	*W*	*lm/W*	*lm*	*lm*	*hr*	
Baseline/0	T12	110	113	80.1	9,050	8,145	12,000	70
Baseline/0	T12	95	97	82.5	8,000	6,950	12,000	62
1	T12	110	113	83.2	9,400	8,648	12,000	80
2	T12	95	97	86.1	8,350	7,515	12,000	70
3	T12	95	97	87.6	8,500	7,650	12,000	80
3	T12	95	97	88.9	8,625	7,750	12,000	85
4	T8	86	86	91.9	7,900	7,100	24,000	78
4	T8	86	86	93.0	8,000	7,200	18,000	75
5	T8	86	86	95.3	8,200	7,800	18,000	86

As seen above, DOE used commercially-available lamps and their associated rated efficacies (rated initial lumen output divided by the ANSI rated wattage) to determine the design options required to meet each efficacy level. However, to establish the minimum efficacy requirements for each efficacy level, DOE coupled catalog data on commercially-available lamps with data submitted to DOE by manufacturers for the purpose of compliance with existing energy conservation standards for general service fluorescent lamps. DOE's use of compliance report data is discussed in further detail in section 5.3.1.2.

As discussed in section 5.3.1.2, DOE considered only recent compliance report data in establishing minimum efficacy requirements. Figure 5.3.26 depicts compliance report data from the years 2007 and 2008 in gray circles. For 8-foot RDC HO lamps, DOE found that not enough data existed from compliance reports submitted in 2007 and 2008 to establish several of efficacy levels with reasonable certainty. Therefore, DOE adjusted these levels to reflect the minimum efficacy requirements recommended by NEMA in their written comments. Table 5.3.23 summarizes the resulting efficacy requirements for 8-foot RDC HO lamps with CCTs less than or equal to 4,500K, after accounting for compliance data.

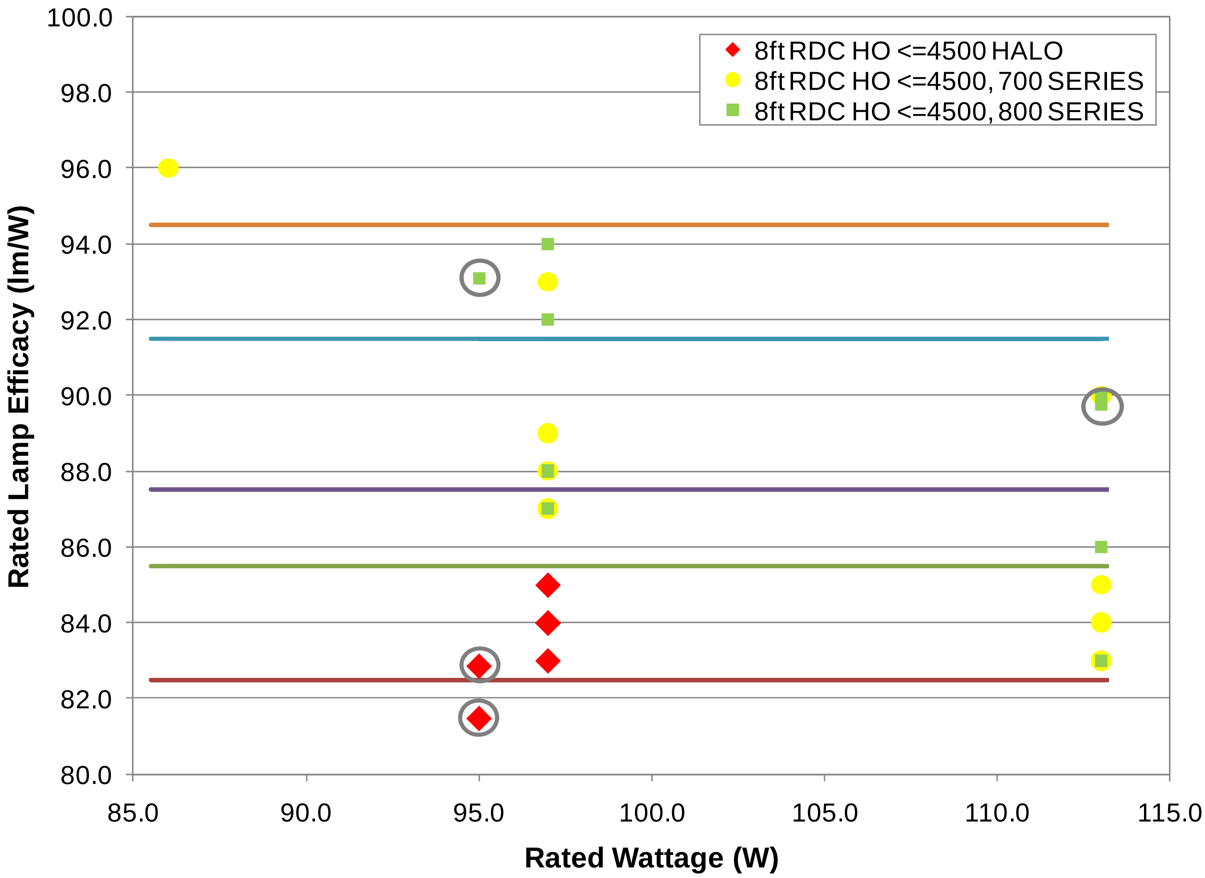

Figure 5.3.26 All Compliance Report Data for 8-Foot RDC HO Lamps with CCTs ≤ 4,500K

Table 5.3.23 Summary of the ELs for 8-Foot RDC HO Lamps With CCTs ≤ 4,500K

Efficacy Level	**Efficacy Requirement** ***lm/W***
EL1	83
EL2	86
EL3	88
EL4	92
EL5	95

Section 5.3.3.4 presents additional information on the lamp-and-ballast systems DOE develops in the engineering analysis.

5.3.3.3 System Power Rating

For each lamp wattage and ballast type, DOE linearly fit the system power rating of a lamp on several different BFs versus the BF of each ballast. Figure 5.3.27 to Figure 5.3.28 show the linear fit and ballast characteristics DOE used to derive the system power rating for two-lamp, 8-foot T12 RDC HO lamps on electronic ballasts. The fit followed the form of Eq. 5.1 where $SPR = m * BF + b$. The ballasts DOE chose for these calculations typically have a THD less than 20 percent, PF greater than 0.95, and typical BEF. Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages.

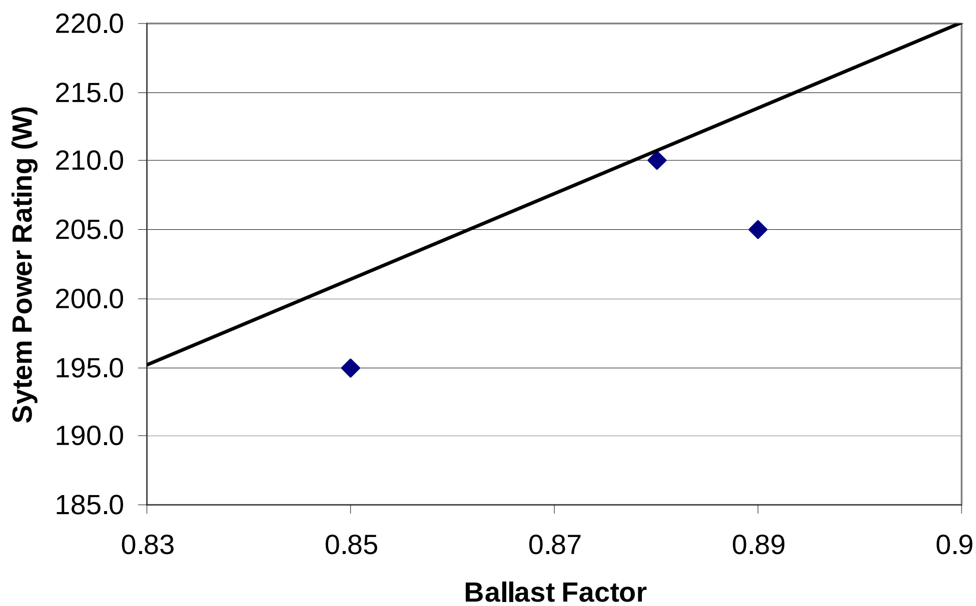

Figure 5.3.27 Two-Lamp 110W T12 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.42-0.43; Linear Fit: m=307.7, b=-65.4

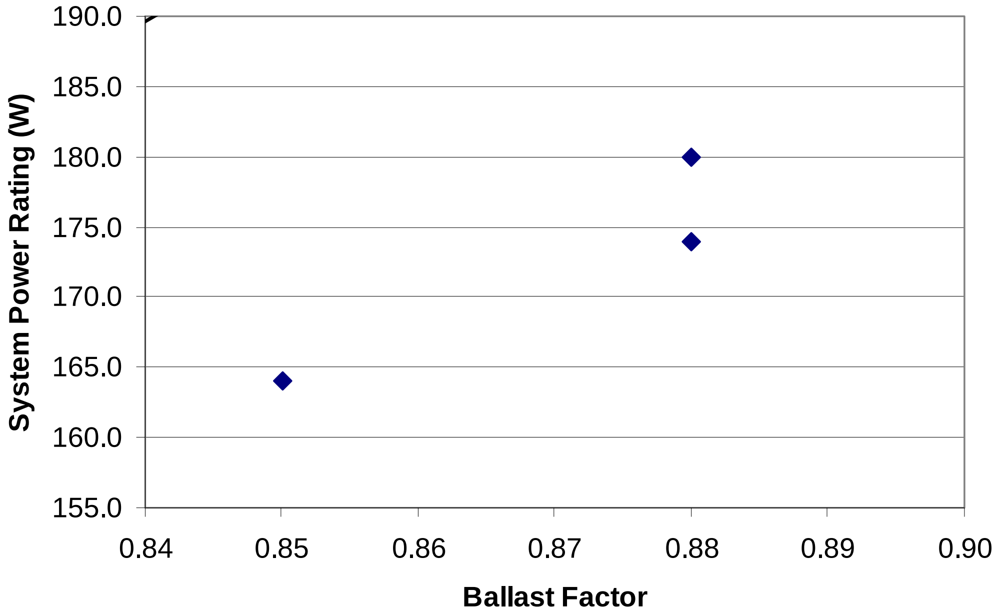

Figure 5.3.28 Two-Lamp 95W T12 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.48-0.52; Linear Fit: m=433.3, b=-204.3

Figure 5.3.29 shows the linear fit and ballast characteristics DOE used to derive the system power rating for two-lamp, 8-foot T8 RDC HO lamps on electronic ballasts. The ballasts DOE used for these calculations typically have a THD less than 20 percent, PF greater than 0.95, and typical BEF.

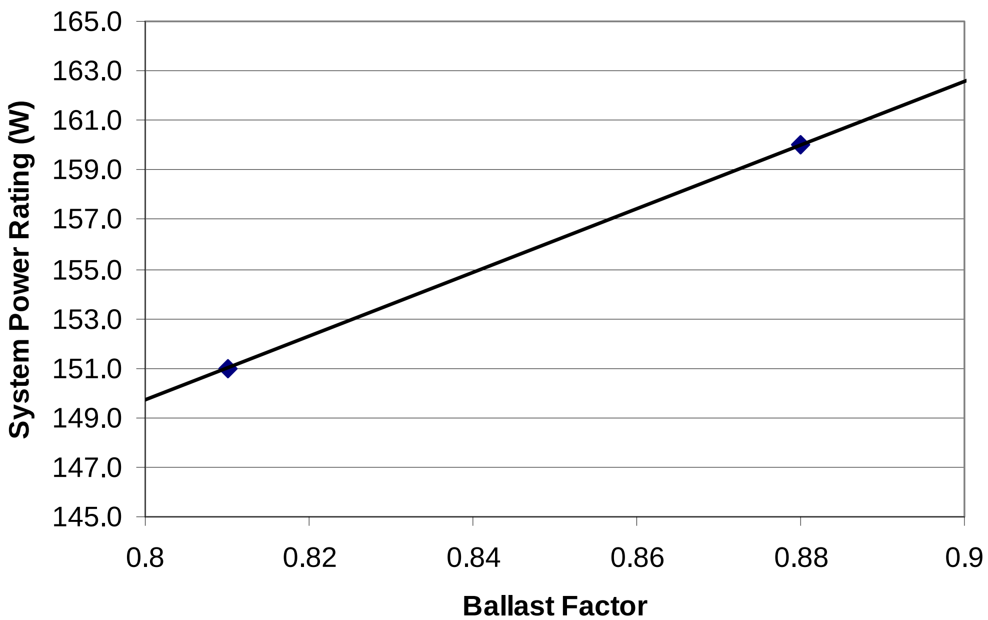

Figure 5.3.29 Two-Lamp 86W T8 120V Ballasts with THD <20 percent, PF >0.95, and BEF 0.54-0.55; Linear Fit: m=128.6, b=46.9

5.3.3.4 Results

DOE evaluated two baseline lamps for the 8-foot RDC HO with CCTs ≤ 4,500K product class: a 110W T12 lamp and a 95W T12 lamp. For each baseline lamp, DOE considered only energy-saving options that result in approximately the same light output as the baseline lamp. Energy savings can either be achieved through lamp replacements or lamp-and-ballast replacements. Additional lamp-and-ballast designs that DOE uses in the NIA are available in appendix 5A.

Table 5.3.24 and Table 5.3.25 present the engineering characteristics of lamp replacement and lamp-and-ballast replacement designs for a baseline 110W 8-foot T12 RDC HO, 4,100K lamp. There are no lamp replacement designs at EL1 because the system lumens of the 95W lamp replacement options below EL3 emit less than 10 percent of the baseline system.

For lamp-and-ballast replacement options, DOE considered some T8 substitutes for the 110W T12 lamp at higher ELs. In events of new construction and renovation, for instance, DOE assumed that some of these 8-foot T8 RDC HO systems will be spaced closer together so that the potential light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system.

As discussed earlier, DOE also adjusted the BF such that the system light output of the lamp-and-ballast design is equal to, greater than, or no more than 10 percent less than the light output of the baseline system.

Table 5.3.24 Lamp Replacement Engineering Analysis for a 110W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	***W***	***lm/W***	***lm***	***lm***	***hr***			***W***	***lm***	***lm***
Baseline	T12	110	113	80.1	9,050	8,145	12,000	Magnetic	0.95	237.0	17,195	15,476
EL3	T12	95	97	87.6	8,500	7,650	12,000	Magnetic	0.91	203.0	15,470	13,923
EL3	T12	95	97	88.9	8,625	7,750	12,000	Magnetic	0.91	203.0	15,698	14,105

Table 5.3.25 Lamp-and-Ballast Replacement Engineering Analysis for a 110W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	110	113	80.1	9,050	8,145	12,000	Magnetic	0.95	237.0	17,195	15,476
EL1	T12	110	113	83.2	9,400	8,648	12,000	Electronic	0.88	205.4	16,544	15,220
EL2*	T12	95	97	86.1	8,350	7,515	12,000	Electronic	0.90	185.6	17,195	15,476
EL2*	T12	95	97	86.1	8,350	7,515	12,000	Magnetic	0.91	203.0	17,195	15,476
EL3	T12	95	97	87.6	8,500	7,650	12,000	Magnetic	0.91	203.0	15,470	13,923
EL3	T12	95	97	88.9	8,625	7,750	12,000	Magnetic	0.91	203.0	15,698	14,105
EL3	T12	95	97	88.9	8,625	7,750	12,000	Electronic	0.90	185.6	15,525	13,950
EL3*	T12	95	97	87.6	8,500	7,650	12,000	Electronic	0.90	185.6	17,195	15,476
EL4*	T8	86	86	91.9	7,900	7,100	24,000	Electronic	0.88	160.0	17,219	15,476
EL4*	T8	86	86	93.0	8,000	7,200	18,000	Electronic	0.81	151.0	17,195	15,476
EL5	T8	86	86	95.3	8,200	7,800	18,000	Electronic	0.88	160.0	14,432	13,728
EL5*	T8	86	86	95.3	8,200	7,800	18,000	Electronic	0.81	151.0	16,269	15,476

* These systems are used only in the new construction/renovation scenario in the LCC analysis. Under this event, slightly more (between 1.12 and 1.33) of these systems are installed where there would have been one baseline system to be within 10 percent mean lumens of the baseline system. Therefore, the LCC and lumen output of these systems are multiplied by a factor (between 1.12 and 1.33) in the LCC analysis.

Table 5.3.26 presents the engineering analysis results for the replacement lamp-and-ballast combinations for the 95W 8-foot T12 RDC HO baseline lamp. DOE did not identify any lower-wattage direct lamp replacement designs that could operate on the same ballast as a 95W T12 and save energy. In this table, DOE considered T8 lamp-and-ballast replacements for the baseline lamp, and selects the BF so that the new system has a light output of no less than 10 percent of the baseline system.

Table 5.3.26 Lamp-and-Ballast Replacement Engineering Analysis for a 95W T12, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T12	95	97	82.5	8,000	6,950	12,000	Magnetic	0.91	203.0	14,560	12,649
EL2	T12	95	97	86.1	8,350	7,515	12,000	Electronic	0.89	181.3	14,863	13,377
EL3	T12	95	97	88.9	8,625	7,750	12,000	Electronic	0.88	177.0	15,180	13,640
EL3	T12	95	97	87.6	8,500	7,650	12,000	Electronic	0.88	177.0	14,960	13,464
EL3	T8	86	86	91.9	7,900	7,100	24,000	Electronic	0.88	160.0	13,904	12,496
EL4	T8	86	86	93.0	8,000	7,200	18,000	Electronic	0.88	160.0	14,080	12,672
EL5	T8	86	86	95.3	8,200	7,800	18,000	Electronic	0.81	151.0	13,284	12,636

5.3.4 Four-foot T5 MiniBP SO GSFL With CCTs ≤ 4,500K

5.3.4.1 Baseline Models

Currently, only 4-foot T5 MiniBP SO lamps utilizing rare-earth phosphors are sold on the US market. DOE recognizes, however, that 4-foot T5 MiniBP SO halophosphor lamps may be introduced to the US market and purchased widely by consumers if efficacy standards for 4-foot T5 MiniBP SO lamps are not established. Because 4-foot T5 halophosphor MiniBP SO lamps do not exist currently, DOE developed a baseline model 4-foot T5 MiniBP SO halophosphor lamp by applying efficacy data from shorter length halophosphor SO T5 lamps that are currently available and creating a relationship between length and efficacy. The baseline 4-foot T5 MiniBP SO lamp that DOE modeled is a 28W halophosphor lamp with an efficacy of 86 lm/W when operated at 35° C. The lamp has a CCT of 4,100K, a CRI of 62, and a rated lifetime of 20,000 hours. Although this lamp is not commercially available today, it is the least efficacious lamp that may be commercially available when standards take effect. For further information on the development of the 4-foot T5 MiniBP SO halophosphor baseline, see appendix 5B of this TSD.

DOE found that a range of ballast factors are available for the 4-foot T5 product classes, and the most common ballast is a 2-lamp ballast. Because the light output of the 4-foot T5 MiniBP SO halophosphor baseline lamp is much lower than T5 lamps sold on the market today, DOE chose the highest ballast factors available. Thus, DOE paired its baseline 4-foot T5 MiniBP SO lamp with 1.15 ballast factor and 1.00 ballast factor programmed-start electronic ballasts. Together, the 28W lamps and 1.00 BF ballast combination creates a lumen package of 3,348 mean lumens (and 4,782 initial lumens), while the 28W lamps and 1.15 BF ballast combination creates a lumen package of 3,850 mean lumens (and 5,499 initial lumens).

Table 5.3.27 Baseline Unit of Analysis for 4-Foot T5 MiniBP Standard-Output Lamps

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy (at 35° C)*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*Lm*	*hr*
T5	28	62	4,100	86.0	2,391	1,674	20,000

* Rated efficacy is based on the rated wattage of the lamp, which is 27.8W.

5.3.4.2 Efficacy Levels

In selecting ELs, DOE considered two different paths to energy savings. The first concentrated on reduced-wattage replacement lamps that could be installed in a socket and operate on the existing ballast. These lower-wattage replacement lamps have a higher efficacy and therefore produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system). The other path to energy savings involved lamps that have the same rated wattage as the baseline lamp, but operate on a new ballast with a different BF, so system energy is lower. DOE selected the BF with the more efficacious lamp to produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system).

For the 4-foot T5 MiniBP SO with CCTs ≤ 4,500K product class DOE analyzed two efficacy levels: the first efficacy level prevents the introduction of less efficacious halophosphor lamps on the market, while the second efficacy level raises the efficacy of the current highest volume 4-foot T5 MiniBP SO lamps on the market.

The following discussion identifies the steps and technologies associated with each EL DOE considered. DOE is aware that many T5 standard-output lamps are operated at 35° C; because DOE is most interested in the efficacy of lamps at typical operating conditions, DOE developed initial efficacy levels for T5 standard-output lamps based on 35° C catalog data. As discussed in the screening analysis (chapter 4), DOE used design options with highly-emissive electrode coatings, higher-efficacy lamp fill gas composition, higher-efficacy phosphors, glass coatings, or higher-efficacy lamp diameter to achieve higher efficacy levels for GSFL. For 4-foot T5 MiniBP SO, the primary design option DOE assessed was the use of higher-efficacy phosphors. No other diameters than T5 were available as design options for this product class. DOE identified the phosphor associated with each EL:

EL1. This efficacy level is characterized by lamps that use 800-series phosphors and have a rated catalog efficacy (initial lamp lumens divided by ANSI rated wattage) of 104 lm/W at 35° C operation. They are the most common 4-foot T5 MiniBP SO lamps currently on the market.

EL2. This level characterizes higher efficacy 4-foot T5 MiniBP SO lamps that use improved 800-series phosphors. Specifically, there is a reduced-wattage (26W) 4-foot T5 MiniBP SO lamp (with a rated efficacy of 112 lm/W at 35° C operation) and a full-wattage (28W) lamp (with a rated efficacy of 110 lm/W at 35° C operation) that are more efficacious than the lamps that just meet efficacy level 1.

Figure 5.3.30 illustrates two initial ELs based on catalog values of commercially-available fluorescent lamps that DOE selected to analyze on a plot of selected fluorescent lamps. A square box and a label identifies the baseline lamp. The plot also shows the high-efficacy replacement lamps DOE is considering for the baseline lamp. Some are at the same wattage as the baseline lamp, but have a higher efficacy; one lamp has a combination of lower wattage and higher efficacy.

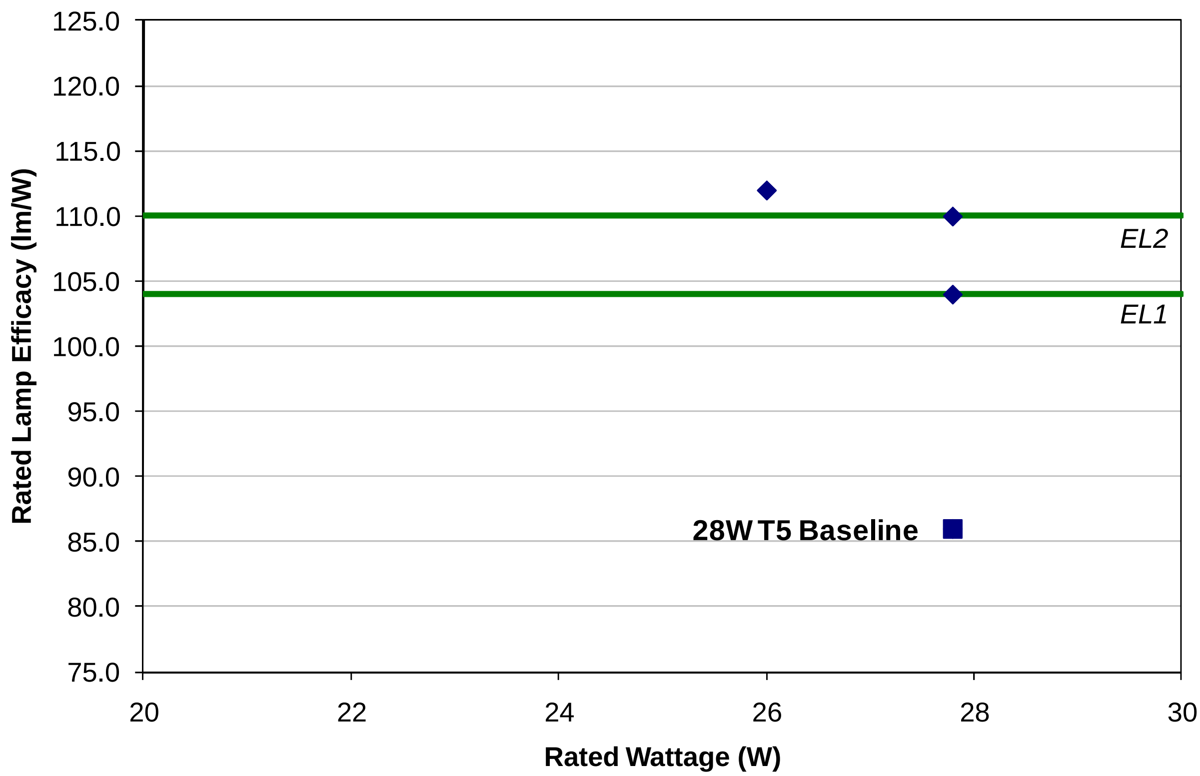

Figure 5.3.30 Initial Efficacy Levels for 4-Foot T5 MiniBP SO Lamps With CCTs ≤ 4,500K, 35° C Operation

Table 5.3.28 provides detailed information on the 4-foot T5 MiniBP SO lamp designs used in the engineering analysis and subsequent analyses.

Table 5.3.28 4-Foot T5 MiniBP SO Lamp Designs

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	CRI
		W	*W*	*lm/W*	*Lm*	*lm*	*hr*	
Baseline/0	T5	28	27.8	86.0	2,391	1,674	20,000	62
1	T5	28	27.8	104.3	2,900	2,660	20,000	85
2	T5	28	27.8	109.7	3,050	2,898	20,000	85
2	T5	26	26.0	111.5	2,900	2,660	25,000	85

As seen above, DOE used commercially-available lamps and their associated rated efficacies (rated initial lumen output divided by the ANSI rated wattage) to determine the design options required to meet each efficacy level. However, similar to previously discussed product classes, these rated efficacy values do not necessarily correspond to how these lamps may comply under energy conservation standards. As discussed further detail in section 5.3.1.2, DOE used compliance report data to establish minimum efficacy requirements for the 4-foot MBP, 8-

foot SP slimline, and 8-foot RDC HO efficacy levels. Because 4-foot MiniBP SO lamps have been not been regulated by DOE in the past, 4-foot MiniBP SO compliance reports do not exist. Therefore, to establish appropriate minimum efficacy requirements for each 4-foot MiniBP efficacy level, DOE computed the percentage difference between the rated efficacy and compliance efficacy for the highest-efficacy 4-foot MBP lamps, and applied that same percentage reduction to the 4-foot T5 MiniBP SO rated efficacies. In addition, the DOE test procedure for T5 lamps requires the lamps to be tested at 25°C. When operated at 25°C, the lumen output of T5 lamps is approximately 10 percent lower than the lumen output of such lamps when operated at 35° C. Because the test procedure will be used to determine compliance with DOE energy conservation standards, DOE developed EL requirements for T5 standard-output lamps that take into account 25° C testing. Table 5.3.29 summarizes the resulting efficacy levels for 4-foot MiniBP SO lamps with CCTs less than or equal to 4,500K, taking compliance data and 25° C testing into account.

Table 5.3.29 Summary of the ELs for 4-Foot T5 MiniBP SO Lamps With CCTs ≤ 4,500K

Efficacy Level	Efficacy Requirement *lm/W*
EL1	86
EL2	90

Section 5.3.4.4 presents additional information on the lamp-and-ballast systems DOE develops in the engineering analysis.

5.3.4.3 System Power Rating

DOE calculated the system power rating, which represents the energy consumption rate of both the lamps and ballast, using published catalog information. For each lamp wattage and ballast type, DOE applied a linear fit to several points identifying the system power rating of a lamp on a ballast and the ballast factor of the ballast. The fit follows the form of Eq. 5.1 where $SPR = m * BF + b$. DOE used a linear form because the relationship is approximately linear over the range of BFs and wattages considered.

The ballasts DOE used typically have a total harmonic distortion (THD) less than 10 percent, power factors (PF) greater than 0.95, and typical ballast efficacy factors (BEF). Because ballast efficiencies naturally increase as lamp wattages decrease, there is a natural progression to higher typical BEFs at lower wattages. Also, because there is less manufacturer literature on system power ratings of ballasts with lower wattage lamps, DOE used fewer points to develop a linear fit for the energy-saving lamp wattages. Figure 5.3.31 to Figure 5.3.32 show the linear fit and ballast characteristics DOE used to derive the system power rating for 2-lamp, 4-foot T5 SO lamps on electronic ballasts.

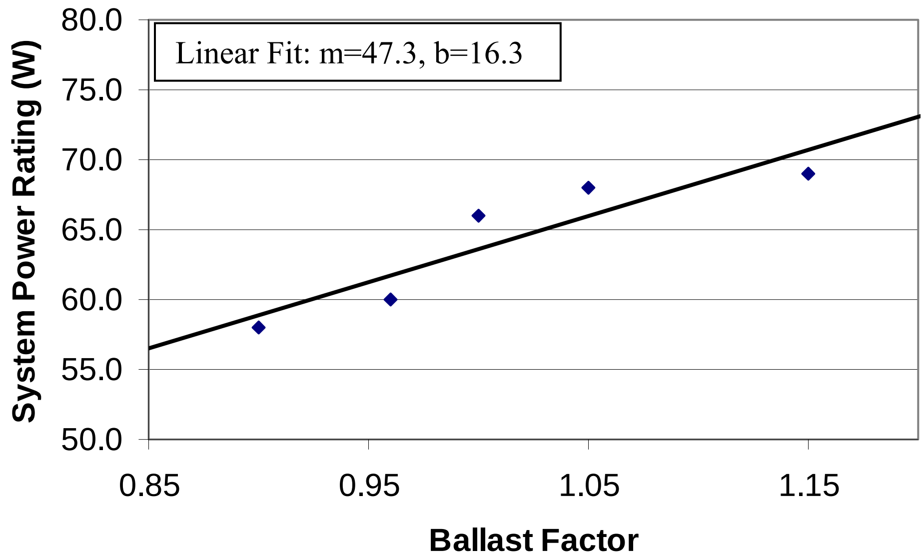

Figure 5.3.31 Two-Lamp 28W T5 Ballasts with THD <10 percent, PF >0.95, and BEF 1.52-1.67

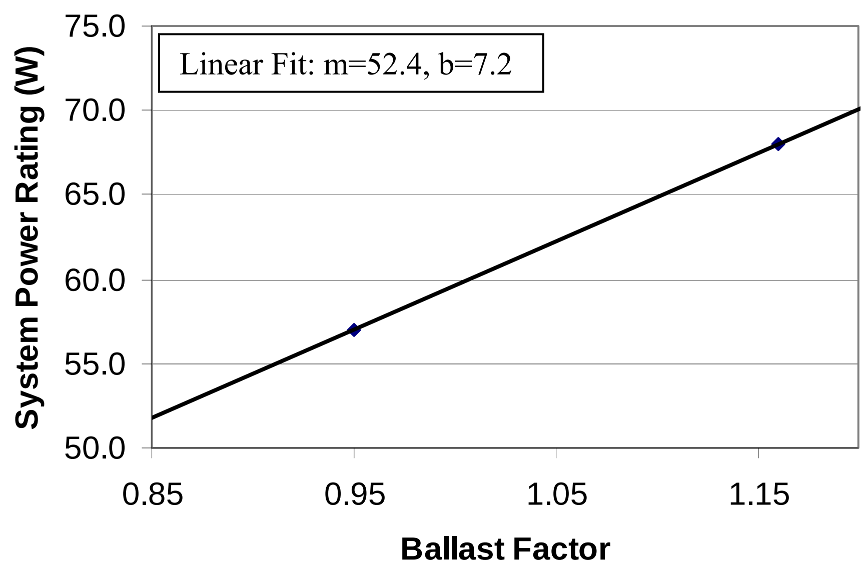

Figure 5.3.32 Two-Lamp 26W T5 Ballasts with THD <10 percent, PF >0.95, and BEF 1.67-1.71

5.3.4.4 Results

For the 4-foot T5 MiniBP SO with CCTs ≤ 4,500K product class, DOE assessed one model baseline lamp. DOE considered only energy-saving options that result in approximately the same light output as the baseline lamp system. Energy savings could either be achieved through lamp or lamp and ballast replacements. Appendix 5A provides information on the additional lamp-and-ballast designs DOE uses in the NIA.

Table 5.3.30 presents the engineering characteristics of lamp replacement options for a baseline 28W 4-foot T5 MiniBP SO, 4,100K lamp. Table 5.3.31 presents the engineering characteristics of lamp and ballast replacement options for the same lamp. As discussed earlier, DOE adjusted the BF so that the combination of lamp and ballast maintains light output so that potential light output is equal to, greater than, or no more than 10 percent less than the light output of the baseline system. All T5 ballasts that DOE considered are electronic.

Table 5.3.30 Lamp Replacement Engineering Analysis for a Two-Lamp 28W T5, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T5	28	27.8	86.0	2,391	1,674	20,000	Electronic	1.15	70.7	5,499	3,850
EL2	T5	26	26.0	111.5	2,900	2,660	25,000	Electronic	1.15	67.5	6,670	6,118

Table 5.3.31 Lamp and Ballast Replacement Engineering Analysis for a Two-Lamp 28W T5, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	*W*	*Lm/W*	*lm*	*lm*	*hr*			*W*	*lm*	*lm*
Baseline	T5	28	27.8	86.0	2,391	1,674	20,000	Electronic	1.15	70.7	5,499	3,850
EL1*	T5	28	27.8	104.3	2,900	2,660	20,000	Electronic	0.96	61.2	5,510	5,054
EL2*	T5	28	27.8	109.7	3,050	2,898	20,000	Electronic	0.90	109.7	5,490	5,216
EL2*	T5	26	26.0	111.5	2,900	2,660	25,000	Electronic	0.90	54.4	5,220	4,788

* These systems are used in the new construction/renovation scenario in the LCC analysis. Under this event, slightly less (between 0.74 and 0.80) of these systems are installed where there would have been one baseline system to be within 10 percent mean lumens of the baseline system. Therefore, the LCC and lumen output of these systems are multiplied by a factor (between 0.74 and 0.80) in the LCC analysis.

5.3.5 Four-foot T5 MiniBP HO GSFL With CCTs ≤ 4,500K

5.3.5.1 Baseline Models

Similar to 4-foot T5 MiniBP SO lamps, currently, only 4-foot T5 MiniBP HO lamps utilizing rare-earth phosphors are sold on the US market. DOE recognizes, however, that 4-foot T5 MiniBP HO halophosphor lamps may be introduced to the US market and purchased widely by consumers if efficacy standards for 4-foot T5 MiniBP HO lamps are not established. Because 4-foot T5 halophosphor MiniBP HO lamps do not exist currently, DOE developed a baseline model 4-foot T5 MiniBP HO halophosphor lamp by applying efficacy data from shorter length halophosphor fluorescent T5 lamps that are currently available in the market and creating a relationship between length and efficacy. The baseline 4-foot T5 MiniBP HO lamp that DOE modeled is a 54W halophosphor lamp with an efficacy of 76.6 lm/W at 35° C operation. The lamp has a CCT of 4,100K, a CRI of 62, and a rated lifetime of 20,000 hours. Although this lamp is not commercially available today, it is the least efficacious lamp that may be commercially available when standards take effect. For further information on the development of the 4-foot T5 MiniBP HO halophosphor baseline, see appendix 5B of this TSD.

DOE found that the most common ballast is a 2-lamp ballast with a 1.0 ballast factor. Thus, DOE paired its baseline 4-foot T5 MiniBP HO lamp with a 1.00 ballast factor programmed start electronic ballast. Together, the 54W lamps and 1.00 BF ballast combination creates a lumen package of 5,770 mean lumens (and 8,244 initial lumens).

Table 5.3.32 Baseline Unit of Analysis for 4-Foot T5 MiniBP High-Output Lamps

Lamp Diameter	Nominal Wattage	CRI	CCT	Rated Efficacy (at 35° C)*	Initial Light Output	Mean Light Output	Life
	W		*K*	*lm/W*	*lm*	*Lm*	*hr*
T5	54	62	4,100	76.6	4,122	2,885	20,000

* Rated efficacy is based on the rated wattage of the lamp, which is 53.8W.

5.3.5.2 Efficacy Levels

In selecting ELs, DOE considered two paths to energy savings. The first concentrated on reduced wattage replacement lamps that could be installed in a socket and operate on the existing ballast. These lower-wattage replacement lamps have a higher efficacy and therefore produce approximately the same light output as the baseline lamp (i.e., light output never drops below 10 percent of the baseline system). The other path to energy savings involves installing a higher efficacy lamp on the same ballast factor ballast to increase light output. For new construction, users can install fewer lamp-and-ballast systems in the case of a standard due to their higher light output. DOE could not consider installing a lamp on a lower ballast factor ballast to save energy as ballasts with a ballast factor lower than 1.0 are not commercially available.

For the 4-foot T5 miniature bipin HO with CCTs ≤ 4,500K product class DOE analyzed one efficacy level preventing the introduction of less efficacious halophosphor lamps on the market. For the 4-foot T5 MiniBP HO with CCTs ≤ 4,500K product class, DOE found that only one full-wattage (54W) lamp exists on the market today. Because DOE based its ELs on full-wattage lamps due to the limited utility of reduced-wattage lamps, DOE did not analyze an additional EL for this product class. DOE, however, was able to identify a reduced-wattage lamp and a full-wattage 4-foot T5 MiniBP HO lamp featuring 800-series phosphors.

The following discussion identifies the steps and technologies associated with the EL DOE considered. Because DOE believes that many T5 high-output lamps are operated at 35° C, DOE developed an efficacy level that reflects 35° C operation. As discussed in the screening analysis (chapter 4), DOE used design options with highly-emissive electrode coatings, higher-efficacy lamp fill gas composition, higher-efficacy phosphors, glass coatings, or higher-efficacy lamp diameter to achieve higher efficacy levels for GSFL. For 4-foot T5 MiniBP HO lamps, the primary design option DOE assessed was the usage of higher-efficacy phosphors. DOE also identified the phosphor associated with the EL:

EL1. This efficacy level is characterized by lamps that use 800-series phosphors. There is a full-wattage (54W) lamp with a rated catalog efficacy (initial lamp lumens divided by ANSI rated wattage) of 92.9 lm/W at 35° C and a reduced-wattage (51W) lamp with a rated catalog efficacy of 98.0 lm/W at 35° C.

Figure 5.3.33 illustrates an initial EL based on catalog values of commercially-available fluorescent lamps on a plot of selected fluorescent lamps. A square box and a label identify the baseline lamp. The plot also shows the high-efficacy replacement lamps DOE considered for the baseline lamp. One is at the same wattage, but has a higher efficacy; the other has a combination of lower wattage and higher efficacy.

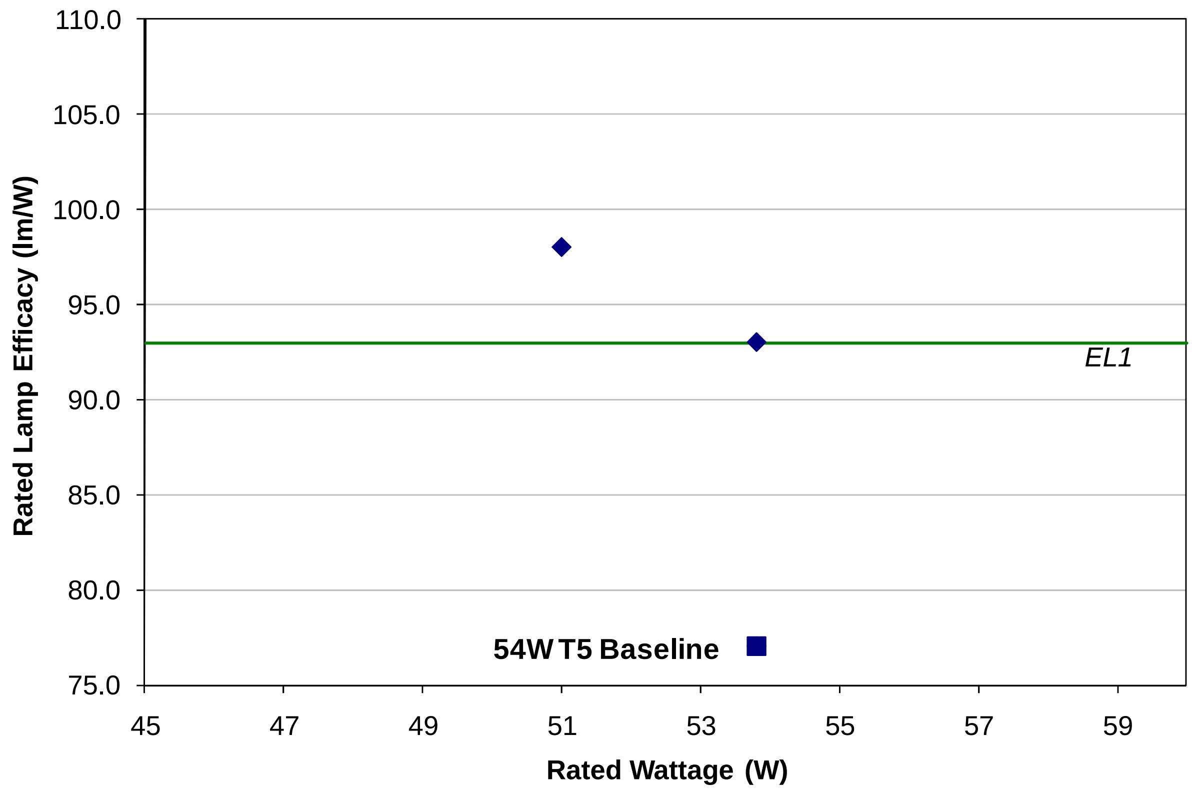

Figure 5.3.33 Initial Efficacy Level for 4-Foot T5 MiniBP HO Fluorescent Lamps With CCTs ≤ 4,500K, 35° C Operation

Table 5.3.33 provides detailed information on the 4-foot T5 MiniBP HO lamp designs used in the engineering analysis and subsequent analyses.

Table 5.3.33 4-Foot T5 MiniBP HO Lamp Designs

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	CRI
		W	*W*	*lm/W*	*lm*	*lm*	*hr*	
Baseline/0	T5	54	53.8	76.6	4,122	2,885	20,000	62
1	T5	54	53.8	92.9	5,000	4,600	20,000	85
1	T5	51	51.0	98.0	5,000	4,600	20,000	85

As seen above, DOE used commercially-available lamps and their associated rated efficacies (rated initial lumen output divided by the ANSI rated wattage) to determine the design options required to meet each efficacy level. However, similar to previously discussed product classes, these rated efficacy values do not necessarily correspond to how these lamps may comply under energy conservation standards. As discussed further detail in section 5.3.1.2, DOE used compliance report data to establish minimum efficacy requirements for the 4-foot MBP, 8-foot SP slimline, and 8-foot RDC HO efficacy levels. Because 4-foot MiniBP HO lamps have been not been regulated by DOE in the past, 4-foot MiniBP HO compliance reports do not exist. Therefore, to establish appropriate minimum efficacy requirements for each 4-foot MiniBP efficacy level, DOE calculated the percentage difference between the rated efficacy and compliance efficacy for the highest-efficacy 4-foot MBP lamps, and applied that same percentage reduction to the 4-foot T5 MiniBP HO rated efficacies. In addition, the DOE test procedure for T5 lamps requires the lamps to be tested at 25°C. When operated at 25°C, the lumen output of T5 lamps is approximately 10 percent lower than the lumen output of such lamps when operated at 35° C. Because the test procedure will be used to determine compliance with DOE energy conservation standards, DOE developed EL requirements for T5 high-output lamps that take into account 25° C testing. Table 5.3.34 summarizes the resulting efficacy level for 4-foot MiniBP HO lamps with CCTs less than or equal to 4,500K.

Table 5.3.34 Summary of the ELs for 4-Foot T5 MiniBP HO Lamps With CCTs ≤ 4,500K

Efficacy Level	Efficacy Requirement *lm/W*
EL1	76

Section 5.3.5.4 presents additional information on the lamp-and-ballast systems DOE develops in the engineering analysis.

5.3.5.3 System Power Rating

The ballasts DOE used typically have a total harmonic distortion less than 10 percent, power factors greater than 0.95, and typical ballast efficacy factors. The 54W lamp has one available ballast that results in a system power rating of 120.0W during 35° C operation, while the 51W lamp has one available ballast that results in a system power rating of 117.0W during 35° C operation.

5.3.5.4 Results

For the 4-foot T5 MiniBP HO with CCTs ≤ 4,500K product class, DOE assessed one model baseline lamp. DOE considered only energy-saving options that result in approximately the same light output as the baseline lamp system. Energy savings could either be achieved through lamp or lamp and ballast replacements.

Table 5.3.35 presents the engineering characteristics of lamp replacement options for a baseline 54W 4-foot T5 MiniBP HO, 4,100K lamp. Table 5.3.36 presents the engineering characteristics of lamp and ballast replacement options for the same lamp. As discussed earlier, DOE adjusted the BF so that the combination of lamp and ballast maintains light output that is equal to, greater than, or no more than 10 percent less than the light output of the baseline system. All T5 ballasts that DOE considered are electronic.

Table 5.3.35 Lamp Replacement Engineering Analysis for a Two-Lamp 54W T5, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	***W***	***lm/W***	***lm***	***lm***	***hr***			***W***	***lm***	***lm***
Baseline	T5	54	53.8	76.6	4,122	2,885	20,000	Electronic	1.00	120.0	8.244	5,770
EL1	T5	51	51.0	98.0	5,000	4,600	25,000	Electronic	1.00	117.0	10,000	9,200

Table 5.3.36 Lamp and Ballast Replacement Engineering Analysis for a Two-Lamp 54W T5, 4,100K System

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy (at 35° C)	Initial Light Output	Mean Light Output	Life	Ballast Type	Ballast Factor	System Power Rating	System Initial Light Output	System Mean Light Output
		W	***W***	***Lm/W***	***lm***	***lm***	***hr***			***W***	***lm***	***lm***
Baseline	T5	54	53.8	76.6	4,122	2,885	20,000	Electronic	1.00	120.0	8,244	5,770
EL1*	T5	54	53.8	92.9	5,000	4,600	20,000	Electronic	1.00	120.0	6,272	5,770
EL1	T5	51	51.0	98.0	5,000	4,600	25,000	Electronic	1.00	117.0	10,000	9,200
EL1*	T5	51	51.0	98.0	5,000	4,600	25,000	Electronic	1.00	117.0	6,272	5,770

* These systems are used in the new construction/renovation scenario in the LCC analysis. Under this event, slightly less (0.63) of these systems are installed where there would have been one baseline system to be within 10 percent mean lumens of the baseline system. Therefore, the LCC and lumen output of these systems are multiplied by a factor (0.63) in the LCC analysis.

5.4 INCANDESCENT REFLECTOR LAMPS

As discussed in chapter 3, the market and technology assessment, DOE created eight separate incandescent reflector lamp product classes with three subdivisions: standard-spectrum IRL and modified-spectrum IRL, diameter greater and less than or equal to 2.5 inches, and voltage less than and greater than or equal to 125V. DOE chose to analyze the standard-spectrum, voltage less than 125V, diameter greater than 2.5 inches IRL product class due to its prevalence in the market. Discussions with industry experts and a review of manufacturer literature for IRL revealed that standard-spectrum lamps represent the vast majority of IRL. Discussions also revealed that the majority of consumers purchase 120V PAR30 or PAR38 IRL (the most common lamps with a diameter greater than 2.5 inches). Modified-spectrum IRL, PAR20 IRL (the most common lamps with a diameter less than or equal to 2.5 inches) and IRL that operate at 130V are not as common in the marketplace. Thus, DOE extrapolated its findings on standard-spectrum 120V IRL with diameters greater than 2.5 inches to the other product classes. Section 5.5.2 provides details on this extrapolation.

Each IRL product class considered spans the full range of wattages covered. DOE considered ELs for each product class with efficacy that varies with wattage. Given that the IRL product classes are not divided by wattage, DOE did not choose a representative wattage bin for IRL. However, rather than selecting one baseline lamp, DOE chose to analyze lamps of multiple wattages in the standard-spectrum product class to prevent oversimplification of the analysis. DOE concentrated on analyzing the most popular reflector lamps in terms of lamp size, wattage, and lumen package. DOE examined existing product on the market at multiple wattages to select baseline lamps. DOE used product at multiple wattages to derive efficacy equations that span wattage. Therefore, DOE was able to apply the analysis performed on the most popular lamps to the other, less-common lamps. Section 5.4.2 provides further details on the ELs DOE developed for IRL.

Table 5.4.1 Product Classes for Incandescent Reflector Lamps

Lamp Type	Diameter	Voltage
Standard-spectrum	> 2.5 inches	≥ 125
		< 125 (representative)
	≤ 2.5 inches	≥ 125
		< 125
Modified-spectrum	> 2.5 inches	≥ 125
		< 125
	≤ 2.5 inches	≥ 125
		< 125

As with GSFL, DOE analyzed lamp designs for the LCC that both save energy and maintain comparable light output. DOE considered lamp designs that emit initial lumens equal to the light output of the baseline system, or less than that system by no more than 10 percent. DOE maintained light output across efficacy levels to ensure that products supply equivalent service under the base case and standards case scenarios. To account for the purchase of more-efficacious lamps at the same wattage as the baseline lamp wattage (thus with greater light output), DOE considered non-energy-saving lamps in the NIA. Appendix 5A shows lamp designs considered in the NIA.

In assessing light output, DOE distinguished between mean and initial lumens. DOE used initial lumens in its test procedures for incandescent lamps to measure compliance with a standard. This is consistent with consensus industry standards on efficacy measurements. Therefore, DOE used initial lumens to calculate efficacy. For incandescent lamps, DOE also used initial lumens when predicting consumer purchase decisions. Consumers generally make purchase decisions based on initial lumens and not mean lumens for incandescent lamps. Therefore, DOE lists initial lumens in its tables. Over time, the light output of an incandescent lamp decreases slightly. To account for this real-world depreciation in lumens, DOE also monitored mean lumens in the NIA.

5.4.1 Baseline Models for IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Less Than 125V

DOE selected three baseline lamps of varying wattage and shapes to provide a comprehensive understanding of consumer economics. DOE included parabolic reflector (PAR) halogen baseline lamps of three different wattages. These baseline lamps are currently regulated by EPCA and meet the EPCA standard.

DOE identified three IRL lumen packages that are popular in the commercial and residential sectors. DOE also identified power ratings and lifetime characteristics of these lamps, as listed in Table 5.4.2. The three light output packages are 630, 1050, and 1,310 lumens, corresponding to a 50W PAR30, 75W PAR38, and 90W PAR38 lamp, respectively. These lamps represent the most common reflector lamps sold and used today; thus, they represent high-volume wattages and diameters. Since these lamps capture a range of wattages, lumen packages, and lamp diameters, they cover a range of applications. Table 5.4.2 presents the representative product class and the three baseline lamps DOE selected for its IRL analysis.

Table 5.4.2 IRL Representative Product Class and Baseline Lamps

Lamp Category	**Representative Product Class**	**Representative Product Class Baseline Lamps**				
		Descriptor	Wattage ***W***	Efficacy ***lm/W***	Initial Light Output ***lm***	Lifetime ***hr***
IRL	Standard-Spectrum, Voltage < 125V, Diameter > 2.5 Inches	PAR30 PAR38 PAR38	50 75 90	12.6 14.0 14.6	630 1,050 1,310	3,000 2,500 2,500

5.4.2 Efficacy Levels

For IRL with diameters greater than 2.5 inches and operating voltages less than 125V, DOE observed natural efficacy divisions in the marketplace corresponding to a variety of design options utilized to increase lamp efficacy. DOE considered these efficacy divisions in selecting ELs by using the efficacy levels of commercially-available lamps as a guide. However, commercially-available product does not exist at all of the ELs for all of the lumen packages. For example, the 50W PAR30 baseline lamp with 630 lumens only has commercially-available product at two of the five ELs. Because it is technically feasible to incorporate the commercially-available technologies in lamp types that correspond to all of the baseline lamps, and to have a continuous range of efficacies to analyze, DOE developed some model IRL based on commercially-available lamp lumen packages. Using efficacy information for the commercially-available lamp designs (which substitute for certain baseline lamps) or efficacy information from manufacturer interviews, DOE developed a relationship between efficacy and wattage. This allowed DOE to develop lamp designs that are not commercially available for certain wattages, but that would be substitutes for other baseline lamps. Generally, the lamp design substitutes for baseline lamps are based around the lumen output of the baseline lamp, plus or minus 10 percent.

In reviewing published catalog data, DOE observed that higher-efficacy, reduced-wattage IRL, which maintain light output within 10 percent, can substitute for a number of baseline lamps. Furthermore, these reduced-wattage designs span a range of design options considered in this rule. These design options, discussed in the screening analysis (chapter 4), include the tungsten-halogen regenerative cycle (hereafter "halogen") and halogen infrared (HIR) technologies that uses both halogen and glass coatings that reflect infrared light.

The commercially-available halogen IRL fall within three tiers of efficacy. To distinguish the efficacies of these halogen IRL, DOE designated them as halogen and improved halogen. Improved halogen can be achieved using xenon, a higher-efficacy inert fill gas. In addition, an even-more-efficacious improved halogen can be achieved by using a silverized reflector, a higher-efficiency reflector coating. The baseline halogen IRL employ neither xenon nor the higher-efficiency reflector coating. DOE also observed four tiers of efficacy for HIR IRL. To distinguish the efficacies of these IRL, DOE designated them as long-life HIR, HIR, improved HIR (4,000 hour), and improved HIR plus (4,200 hour). HIR is more efficacious than long-life HIR due to the higher operating temperature. Improved HIR (4,000 hour) can be achieved by using the additional design options discussed in the screening analysis. These design options include higher-efficacy filaments as well as efficient filament coiling, filament configuration, capsule design, high-pressure capsules, or higher-efficacy reflector coating. Improved HIR plus (4,200 hour) can be achieved with further use of these design options. DOE observed lifetime changes across these reduced-wattage IRL. For example, a halogen IRL typically has a lifetime of around 2,000 to 3,000 hours, while an HIR IRL typically lives for 3,000 to 6,000 hours. DOE maintained the lifetime attributes of the commercially available product for its analysis. DOE also considered the possibility that manufacturers would not produce more efficacious improved HIR or HIR plus products with longer lifetimes than the baseline lamps analyzed by DOE. To incorporate this possibility into its analysis, DOE modeled lamps at EL4 and EL5 that have shorter lifetimes and lower prices than the 4,000 hour and 4,200 hour lamps at these efficacy levels. For the lifetimes, see the efficacy level presentation below. For a discussion of prices, see chapter 7 of this TSD.

DOE established ELs for IRL using an approach similar to the one it uses for GSFL. DOE developed continuous equations that set a minimum efficacy requirement across wattage. Each equation represents the potential efficacy a lamp achieves using a particular design option.

These “technology contour lines” represent the same IRL design option across the wattage range of a product class. For example, an EL based on a halogen design option is a curve rather than a step function, and denotes a halogen standard at all wattages. In general terms, DOE based the ELs on the following progression of design options:

EL1. This efficacy level can be achieved by an improved halogen lamp which utilizes xenon, a higher-efficiency inert fill gas. Such a lamp is currently not commercially available at any of the three lumen packages that DOE analyzed, but is technologically feasible to produce. To create EL1, DOE developed a model of a lamp with xenon gas using information from technical literature and confidential information from manufacturers.

EL2. This efficacy level can be achieved by two lamps: the long-life HIR lamp and the improved halogen lamp with a silver reflector coating. The long-life HIR lamp employs a halogen capsule with an infrared reflective coating and a lamp lifetime of 6,000 hours. An improved halogen lamp that utilizes a silver reflective coating has a lifetime of 3,000 hours.

EL3. This efficacy level can be achieved with an HIR lamp (a lamp containing a halogen capsule with an infrared reflective coating) with a lamp lifetime of 3,000 hours. Decreasing the lamp lifetime from 6,000 to 3,000 hours with higher temperature operation effectively improves the efficacy of the tungsten filament.

EL4. This efficacy level can be achieved by an improved HIR lamp that may employ improved reflector coatings, improved HIR coatings or improved capsule designs. This level is based on an HIR lamp with a lifetime of 4,000 hours. DOE also models an EL4 lamp for the Baseline Lifetime scenario (see chapter 10) that utilizes the same technology but features the same lifetime as the baseline lamp in each lumen package (2,500 hours, 2,500 hours, and 3,000 hours for the 90W, 75W, and 50W lumen packages, respectively).

EL5. This efficacy level can be achieved by the improved HIR plus lamps that may utilize additional improvements in reflector coatings, HIR coatings, or filament and capsule designs that produce higher-temperature operation. This level is based on an HIR lamp with a lifetime of 4,200 hours. DOE also models an EL5 lamp for the Baseline Lifetime scenario that utilizes the same technology as the commercially-available EL 4 lamp but features a lifetime of 2,500 hours for all lumen packages.

Figure 5.4.1 plots the results of the IRL engineering analysis for the three lumen packages (represented by 50W, 75W, and 90W baseline lamps) along with five initial ELs. Square boxes and labels represent the three baseline lamps in the plot; triangles represent higher-efficacy lamp designs. Maintaining light output on this plot of efficacy versus wattage means that lamp designs are always higher in efficacy than the baseline lamp (i.e., moving up on the y-axis) and lower in wattage (i.e., moving to the left on the x-axis). This trend is evident for all three lumen packages analyzed As illustrated in Table 5.4.4 through Table 5.4.6, the Els correspond to efficacy levels associated with lamps with particular design options.

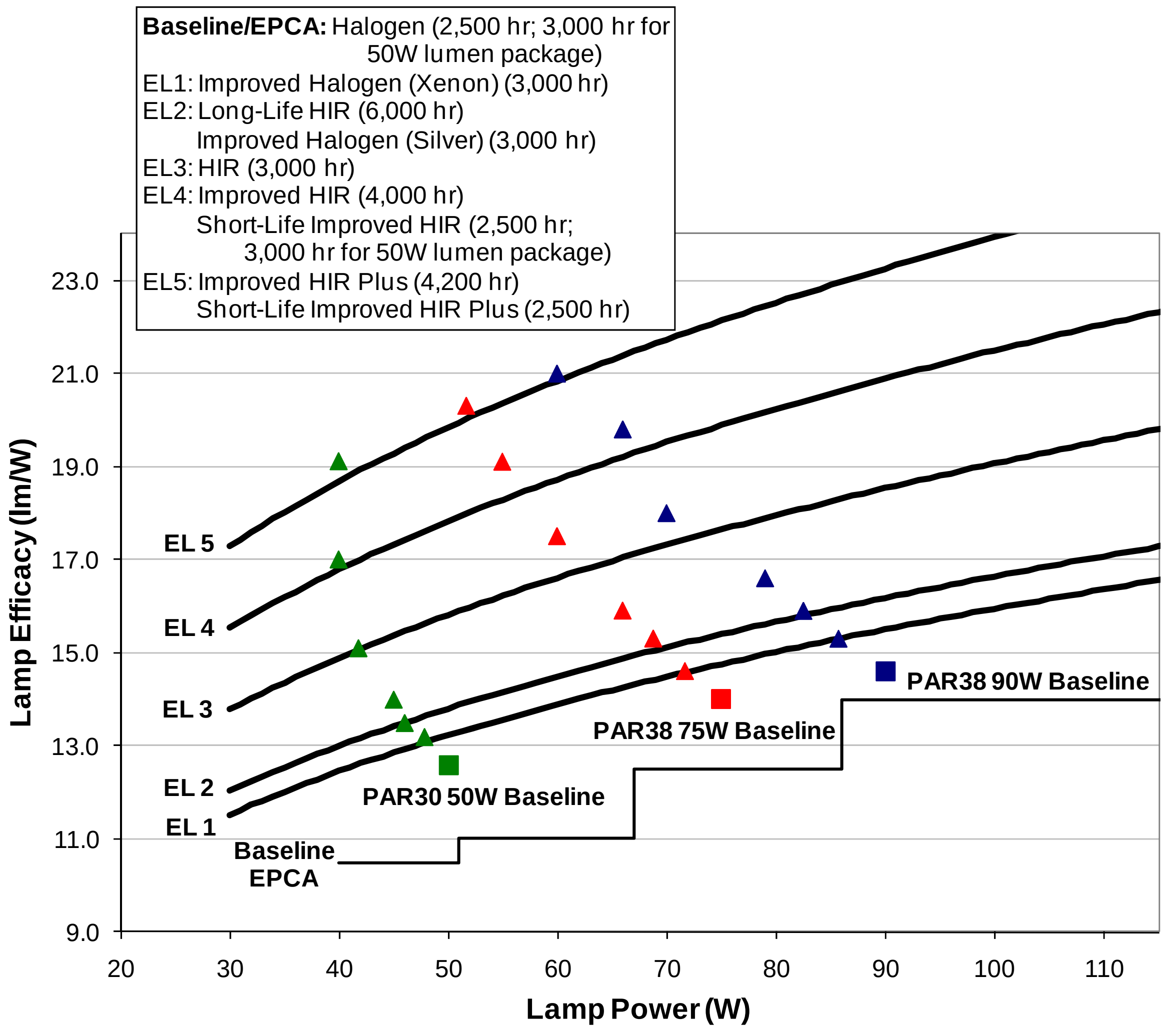

Figure 5.4.1 Initial Efficacy Levels for Standard-Spectrum IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Less Than 125V

As seen above, DOE used the efficacies of commercially-available lamps and model lamps to determine the design options required to meet each efficacy level. However, to establish the minimum efficacy requirements for each efficacy level, DOE coupled catalog data on commercially-available lamps with data submitted to DOE by manufacturers for the purpose of compliance with existing energy conservation standards for incandescent reflector lamps. By analyzing manufacturer compliance reports, DOE found that efficacies of lamps when reported for the purpose of compliance often vary from catalog values.

For these reasons, DOE adjusted the initial efficacy levels for IRL such that commercially available IRL using design options associated with each EL comply with those ELs. Specifically, DOE adjusted EL4 based on the reported efficacy of a PAR38 improved HIR lamp. Also, DOE adjusted EL5 based on the reported efficacies of a PAR38 improved HIR plus lamp as well as a PAR38 improved HIR lamp that DOE analytically increased in efficacy by modeling what the efficacy of the improved HIR lamp (EL4 lamp) would be if the manufacturer shortened the life of the lamp. DOE found that all of the lamps incorporating EL2 and EL3 design options complied with the initial EL2 and EL3 levels, respectively, when the compliance reports for these lamps were taken into account. Thus, DOE did not adjust the initial EL2 or EL3 levels. Because EL1 is based on a model lamp (and thus there are no compliance reports for lamps incorporating the EL1 design options), DOE also did not adjust the EL1 level. Figure 5.4.2 presents the compliance report data used to develop the IRL efficacy levels. Table 5.4.3 shows the resulting efficacy levels for standard-spectrum IRL with diameters greater than 2.5 inches and operating voltages less than 125V.

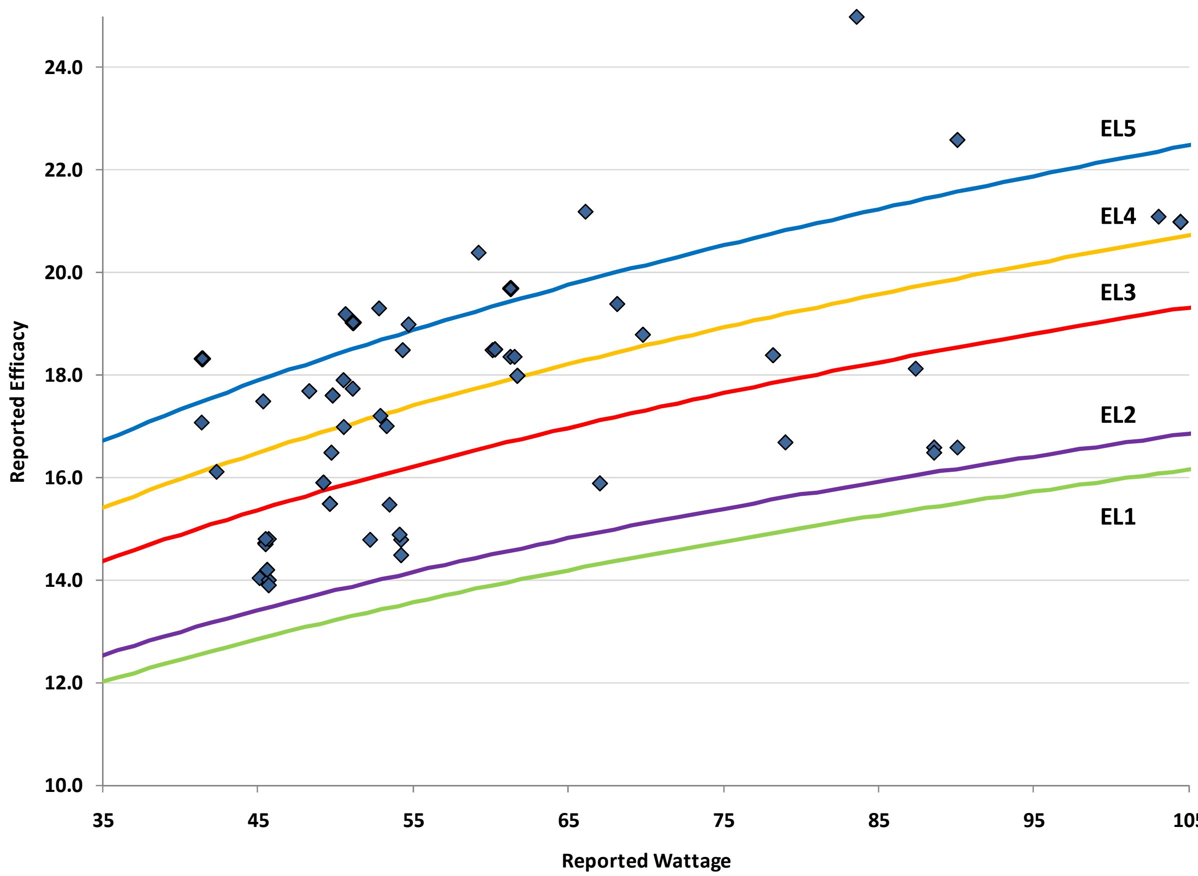

Figure 5.4.2 Compliance Report Data for Standard-Spectrum IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Less Than 125V

Table 5.4.3 Summary of the ELs for Standard-Spectrum IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Less Than 125V

Efficacy Level	Efficacy Requirement
	lm/W
EL1	$4.6P^{0.27}$
EL2	$4.8P^{0.27}$
EL3	$5.4P^{0.27}$
EL4	$5.9P^{0.27}$
EL5	$6.4P^{0.27}$

P = rated wattage

5.4.3 Results

After selecting baseline lamps and ELs, DOE selected lamp designs associated with the ELs for each of the three baseline lamps. Like GSFL, DOE considered IRL that produce more light but do not save energy in the NIA. This reflects the fact that DOE cannot require consumers to switch to a reduced-wattage lamp. Appendix 5A shows the characteristics of lamp designs that both meet the EL and exhibit a higher wattage than or the same wattage as the baseline lamp.

The following table presents the engineering analysis for the 50W PAR30 IRL baseline lamp. This baseline lamp is based on a 630-lumen lamp, plus or minus 10 percent. The 40W improved PAR30 HIR lamp at EL4 and the 46W long-life HIR at EL2 are the only lamps that are commercially available. The 47.8W PAR30 improved halogen (xenon) lamp (EL1), 45W PAR30 improved halogen (silver) lamp (EL2), 41.8W PAR30 HIR (EL3), baseline-life 40.0W PAR30 improved HIR (EL4), and basline- and non-baseline-life 40.0W PAR30 improved HIR plus lamps (EL5) are model lamp designs.[e] These lamps are designed to have approximately the same lumen package as the baseline lamp (i.e., 630 lumens), and to have a minimum efficacy just above each efficacy level.

The 40W improved HIR plus PAR30 produces 21 percent more light output than the 50W PAR30. For the technology employed in these lamps at this efficacy level, DOE believes lamps employing similar design options could not be manufactured (and still achieve similar performance) at wattages below 40W.[f] Therefore, DOE analyzes a 40W lamp that produces greater lumen output at EL5.

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[e] Model lamp designs represent lamps that are not commercially available at this time. DOE developed these lamps based on technical literature and confidential information from manufacturers on incandescent design lamp options. DOE developed these model lamp designs in order to have a more-continuous range of ELs to analyze across the three lumen packages. DOE differentiates between model lamp designs and commercially-available lamp designs by showing the wattage of the model lamp design to the tenths decimal place. Commercially-available lamps are shown in the same way they appear in the product catalogs, with wattages rounded off to the nearest whole number.

[f] Through conversations with technical experts, DOE believes that when operating at 120V, an incandescent filament must become thinner as the wattage of the lamp decreases. When operating at 120V below 40 watts, the filament becomes so thin that its structural integrity becomes compromised. In an HIR lamp, this lower structural integrity causes the filament to produce light in a spot of the reflector lamp that is not ideal for optimum light

Table 5.4.4 IRL Engineering Analysis 50W PAR30

Efficacy Level	Design Option	Lamp Descriptor	Wattage	Efficacy	Initial Light Output	Lamp Life
			W	*lm/W*	*lm*	*hr*
Baseline	Halogen	PAR30	50	12.6	630	3,000
EL1	Improved Halogen (Xenon)*	PAR30	47.8	13.2	630	3,000
EL2	Long-Life HIR	PAR30	46	13.5	620	6,000
EL2	Improved Halogen (Silver)*	PAR30	45.0	14.0	630	3,000
EL3	HIR*	PAR30	41.8	15.1	630	3,000
EL4	Improved HIR	PAR30	40	17.0	680	4,000
EL4	Baseline-Life Improved HIR*	PAR30	40.0	17.0	680	3,000
EL5	Improved HIR Plus*	PAR30	40.0	19.1	765	4,200
EL5	Baseline-Life Improved HIR Plus*	PAR30	40.0	19.1	765	2,500

*IRL lamp designs with an asterisk are model lamp designs.

The following table presents the engineering analysis for the 75W PAR38 IRL baseline lamp. This baseline lamp and its lamp design substitutes are based on a 1,050-lumen lamp, plus or minus 10 percent. DOE developed three model lamps that match the lumen package of this baseline lamp. The 71.7W improved halogen (xenon) PAR38 at EL1 is a model lamp design. DOE used information from technical literature and confidential information from manufacturers to develop this model lamp. In addition, the 68.8W long-life HIR PAR38 lamp at EL2 is a model lamp design. This lamp is based on a 6,000 hour HIR lamp with a different wattage and lumen package. DOE used information from technical literature in order to develop a 6,000 hour HIR lamp with a 1,050-lumen package. The baseline-life improved 55.0W HIR lamp at EL4 is a model lamp design based on a commercially-available improved HIR lamp. The 51.7W improved HIR plus PAR38 lamp at EL5 is a model lamp design that DOE created based on commercially-available HIR lamps with the same lifetime (4,200 hours). Finally, the baseline-life 51.7W improved HIR plus PAR38 lamp at EL5 is a model lamp design that DOE created to have the same lamp lifetime as the baseline lamp (2,500 hours). The improved halogen lamp at EL2 and the lamps at EL3 and EL4 are commercially available.

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extraction. Because of the loss in efficacy due to the placement of the filament in the HIR capsule, it is not practical to produce an HIR IRL below 40W.

Table 5.4.5. IRL Engineering Analysis for 75W PAR38

Efficacy Level	Design Option	Lamp Descriptor	Wattage	Efficacy	Initial Light Output	Lamp Life
			W	***lm/W***	***lm***	***hr***
Baseline	Halogen	PAR38	75	14.0	1,050	2,500
EL1	Improved Halogen (Xenon)*	PAR38	71.7	14.6	1,050	2,500
EL2	Long-Life HIR*	PAR38	68.8	15.3	1,050	6,000
EL2	Improved Halogen (Silver)	PAR38	66	15.9	1,050	3,000
EL3	HIR	PAR38	60	17.5	1,050	3,000
EL4	Improved HIR	PAR38	55	19.1	1,050	4,000
EL4	Baseline-Life Improved HIR*	PAR38	55.0	19.1	1,050	2,500
EL5	Improved HIR Plus*	PAR38	51.7	20.3	1,050	4,200
EL5	Baseline-Life Improved HIR Plus*	PAR38	51.7	20.3	1,050	2,500

*IRL lamp designs with an asterisk are model lamp designs.

The following table presents the engineering analysis for the 90W PAR38 IRL baseline lamp. This baseline lamp and its substitute lamp designs are based on a 1,310-lumen lamp, plus or minus 10 percent. The 85.7W improved halogen (xenon) PAR38 at EL1 is a model lamp design. DOE used information from technical literature and confidential information from manufacturers to develop this model lamp. In addition, the 82.5W long-life HIR PAR38 model lamp at EL2 is a model lamp design. This lamp is based on a 6,000 hour HIR lamp with a different wattage and lumen package. DOE used information from technical literature in order to develop a 6,000 hr HIR lamp with a 1,310 lumen package. The baseline-life and non-baseline-life 66.0W improved HIR PAR38 lamps at EL4 are also model lamp designs. DOE scaled these lamp designs from a relationship between the 75W halogen PAR38 and the 55W improved HIR PAR38. The improved halogen lamp (silver) at EL2, the HIR lamp at EL3, and the non-baseline-life improved HIR plus lamp at EL5 are commercially available. The baseline-life improved HIR plus lamp at EL5 is a model lamp based on the commercially-available improved HIR plus lamp.

Table 5.4.6 IRL Engineering Analysis for 90W PAR38

Efficacy Level	Design Option	Lamp Descriptor	Wattage	Efficacy	Initial Light Output	Lamp Life
			W	*lm/W*	*lm*	*hr*
Baseline	Halogen	PAR38	90	14.6	1,310	2,500
EL1	Improved Halogen*	PAR38	85.7	15.3	1,310	2,500
EL2	Long-Life HIR*	PAR38	82.5	15.9	1,310	6,000
EL2	Improved Halogen	PAR38	79	16.6	1,310	3,000
EL3	HIR	PAR38	70	18.0	1,260	3,000
EL4	Improved HIR*	PAR38	66.0	19.8	1,310	4,000
EL4	Baseline-Life Improved HIR*	PAR38	66.0	19.8	1,310	2,500
EL5	Improved HIR Plus	PAR38	60	21.0	1,260	4,200
EL5	Baseline-Life Improved HIR Plus*	PAR38	60.0	21.0	1,260	2,500

* IRL lamp designs with an asterisk are model lamp designs.

5.5 SCALING TO PRODUCT CLASSES NOT ANALYZED

DOE identified and selected certain product classes as “representative” product classes to concentrate its analytical effort. DOE chose these representative product classes primarily due to their high market volumes. The following section discusses how DOE scales ELs from the analyzed product classes to those product classes that it did not analyze.

5.5.1 General Service Fluorescent Lamps

5.5.1.1 2-foot U-Shaped GSFL With CCTs ≤ 4,500K

Two-foot U-shaped lamps generally are less efficacious than 4-foot MBP lamps due to the bend of a 2-foot U-shaped lamp. This drop in efficacy often depends on the wattage and diameter of the lamp in question. DOE assessed manufacturer catalogs containing commercially-available 2-foot U-shaped lamps with CCTs less than or equal to 4,500K to develop standard levels with a similar technology impact at each EL as 4-foot MBP lamps (see section 5.3.1.2 for these technology impacts). DOE used compliance report data for 2-foot U-shaped lamps to determine the efficacies at which commercially-available products would comply with standards. Figure 5.5.1 shows all compliance report data for 2-foot U-shaped lamps with CCTs less than or equal to 4,500K. The points within the gray circles represent compliance report data submitted in 2007 or 2008.

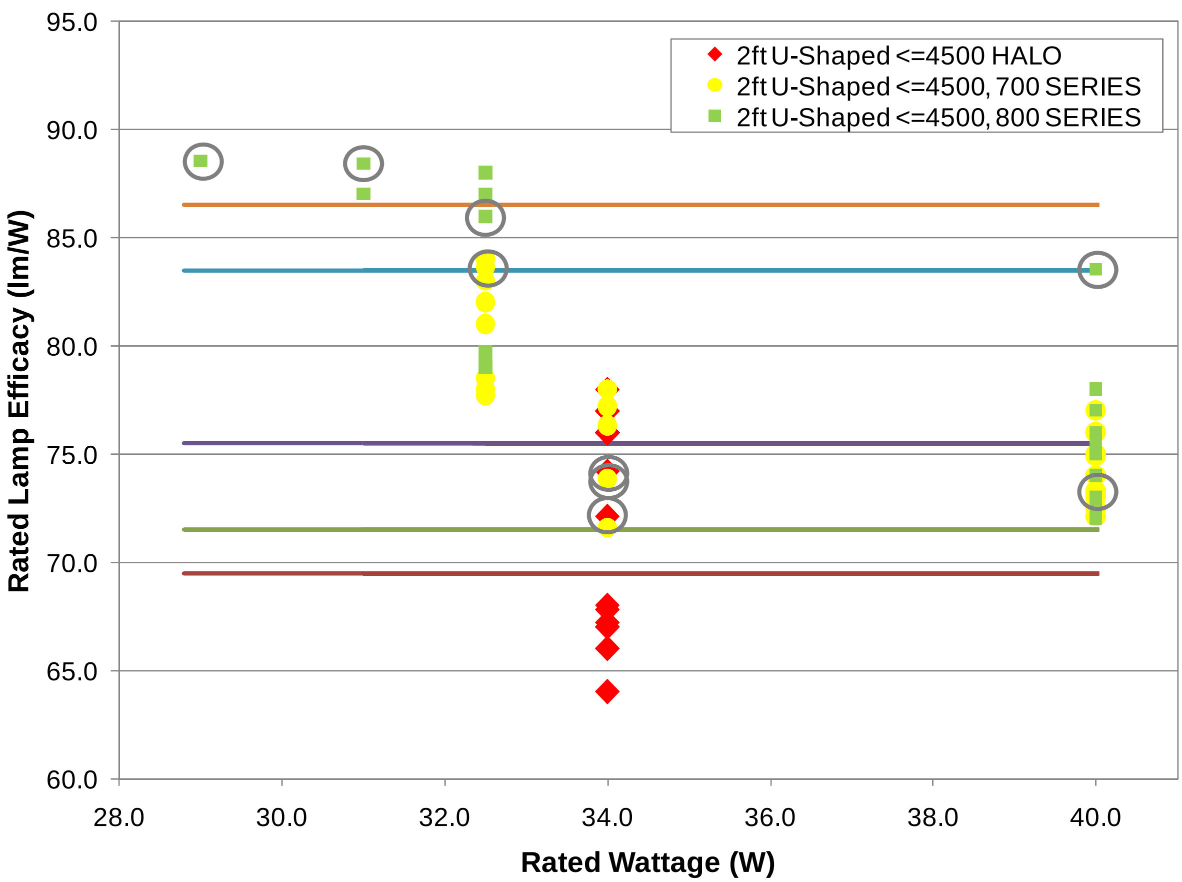

Figure 5.5.1 All Compliance Report Data for 2-Foot U-Shaped Lamps with CCTs ≤ 4,500K

When considering recent compliance report data, as described in section 5.3.1.2, DOE found that not enough data existed from compliance reports submitted in 2007 and 2008 to justify some of its proposed efficacy levels. Specifically, DOE did not have any compliance reports from those years that contained data for U-shaped 34W T12 lamps. Therefore, DOE adjusted EL1 through EL3 to reflect the levels proposed by NEMA in response to the March

2008 ANOPR. (NEMA, No. 26 at p. 7) For EL4 and EL5, NEMA did not propose levels for U-shaped lamps. Thus, DOE used NEMA's suggested 8-percent value as a scaling factor from the linear 4-foot medium bipin efficacy levels. (NEMA, Public Meeting Transcript, No. 38.4 at pp. 123-124) The final efficacy levels for 2-foot U-shaped lamps with CCTs less than or equal to 4,500K are summarized in Table 5.5.1.

Table 5.5.1 Efficacy Requirements for 2-Foot U-Shaped Lamps With CCTs Less Than or Equal To 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	4-foot MBP	2-foot U-Shaped	
1	78	70	10.3%
2	81	72	11.1%
3	85	76	10.6%
4	89	84	5.6%
5	93	87	6.5%

5.5.1.2 Lamps With CCTs Above 4,500K

As discussed in section 5.3, DOE did not analyze GSFL with a CCT above 4,500K and 2-foot U-shaped lamps. As discussed in the market and technology assessment, the efficacy of lamps with higher CCT values is lower due to the quality of blue light emitted. A technical committee of the National Electrical Manufacturers Association analyzed efficacy levels for GSFL product classes and recommended efficacy levels for high CCT lamps.[4] DOE assessed compliance report data for high-CCT lamps when available and compared compliance report data to NEMA's suggestions. For lamps where there was not sufficient compliance report data, DOE adopted NEMA's suggestions. Utilizing this approach, DOE modified its proposed efficacy levels as described below.

Figure 5.5.2 shows all compliance report data for 4-foot MBP lamps with CCTs greater than 4,500K.

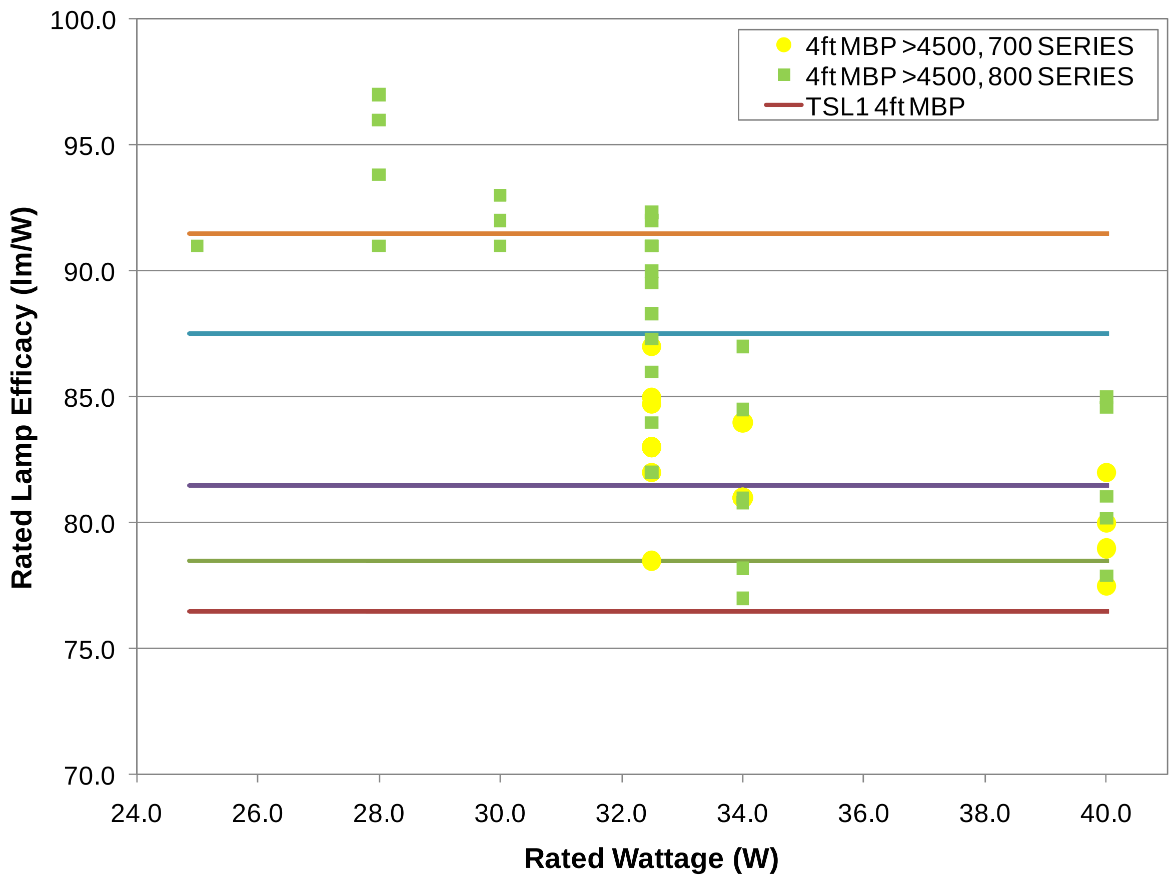

Figure 5.5.2 All Compliance Report Data for 4-Foot MBP Lamps with CCTs > 4,500K

Although DOE obtained compliance reports submitted over the past 15 years, DOE only considered the most recent data when verifying efficacy levels. DOE believes that data contained in compliance reports submitted 2007 and 2008 accurately account for adjustments over the past 15 years to photometry facilities used for NIST and NVLAP testing that have resulted in a reduction of reported lumens for some products. Figure 5.5.3 only shows compliance report data submitted in 2007 and 2008 for 4-foot MBP lamps with CCTs greater than 4,500K.

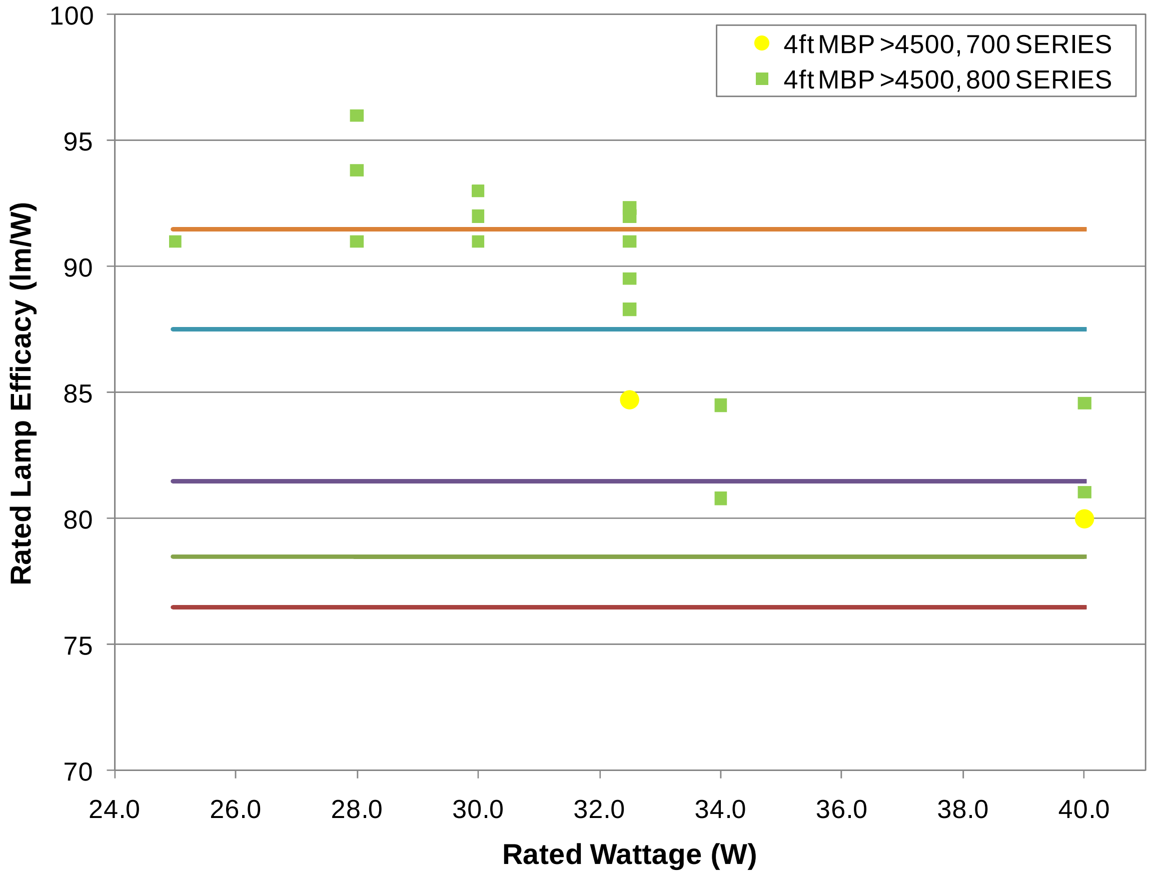

Figure 5.5.3 2007 and 2008 Compliance Report Data for 4-Foot MBP Lamps with CCTs > 4,500K

DOE believes that sufficient data was submitted in 2007 and 2008 to justify its selection of efficacy levels for this representative product class and therefore did not adopt the levels proposed by NEMA. Table 5.5.2 summarizes the resulting efficacy levels for 4-foot MBP lamps with CCTs greater than 4,500K.

Table 5.5.2 Efficacy Requirements For 4-Foot MBP Lamps With CCTs Above 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	78	77	1.3%
2	81	79	2.5%
3	85	82	3.5%
4	89	88	1.1%
5	93	92	1.1%

When considering recent compliance report data for 8-foot lamps, DOE found that not enough data existed from compliance reports submitted in 2007 and 2008 to justify some of its proposed efficacy levels. Specifically, DOE identified EL1, EL2, and EL5 for 8-foot SP slimline lamps and EL2 for 8-foot RDC HO lamps as lacking sufficiently current data. Therefore, DOE adjusted these levels to reflect those levels proposed by NEMA. Table 5.5.3 and Table 5.5.4 summarize the resulting efficacy requirements for 8-foot SP slimline lamps and 8-foot RDC HO lamps with CCTs greater than 4,500K, after accounting for compliance data.

Table 5.5.3 Efficacy Requirements For 8-Foot SP Slimline Lamps With CCTs Above 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	86	83	3.5%
2	92	87	5.4%
3	95	91	4.2%
4	97	93	4.1%
5	98	94	4.1%

Table 5.5.4 Efficacy Requirements For 8-Foot RDC HO Lamps With CCTs Above 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	83	80	3.6%
2	86	83	3.5%
3	88	84	4.5%
4	92	88	4.3%
5	95	91	4.2%

NEMA did not provide efficacy level recommendations for 4-foot T5 MiniBP SO and HO lamps with color temperatures greater than 4,500K. For this reason, DOE reviewed product literature for 4-foot T5 MiniBP SO and HO lamps. By comparing catalog ratings for 4-foot T5 MiniBP SO and HO lamps with a CCT of 4,100K with similar T5 lamps of a 6,500K CCT, DOE determined average efficacy reductions for 4-foot T5 MiniBP SO and HO lamps of high CCT. For 4-foot T5 MiniBP SO lamps of high CCT, DOE reduced EL1 by 6.0 percent to 81 lm/W and EL2 by 6.0 percent to 85 lm/W. For 4-foot T5 MiniBP HO lamps of high CCT, DOE reduced EL1 by 5.0 percent to 72 lm/W. Table 5.5.5 and Table 5.5.6 show the efficacy levels for these lamps.

Table 5.5.5 Efficacy Requirements For 4-Foot T5 MiniBP SO Lamps With CCTs Above 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	86	81	6.0%
2	90	85	6.0%

Table 5.5.6 Efficacy Requirements For 4-Foot T5 MiniBP HO Lamps With CCTs Above 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	76	72	5.0%

For 2-foot U-shaped lamps with CCTs above 4,500K, DOE lacked sufficiently current compliance report data to justify its proposed efficacy levels. NEMA recommended minimum efficacy requirements for EL1 through EL3 only. NEMA, however, also suggested a general scaling factor from linear 4-foot medium bipin levels for U-shaped lamps.[5] DOE used NEMA's suggestions to derive the efficacy levels for 2-foot U-shaped lamps with CCTs greater than 4,500K, as DOE did not have enough compliance data for such lamps to adequately assess manufacturing variability of existing products on the market.

Table 5.5.7 Efficacy Levels For 2-Foot U-Shaped Lamps With CCTs Greater Than 4,500K

EL	Efficacy Requirement (lm/W)		Reduction
	CCT ≤ 4,500K	CCT > 4,500K	
1	70	65	7.1%
2	72	67	6.9%
3	76	71	6.6%
4	84	81	3.6%
5	87	85	2.7%

5.5.2 Incandescent Reflector Lamps

5.5.2.1 Modified-Spectrum IRL

DOE analyzed standard-spectrum lamps, but set separate standards for modified-spectrum IRL. As with higher CCT GSFL, modified-spectrum IRL achieve their modified spectra through selective filtering of the spectra, thereby inherently lowering their efficacies. Manufacturers achieve this specific spectrum in modified-spectrum IRL by applying a coating, or introducing neodymium or other additives into the cover glass of the IRL. Manufacturers may change the thickness of the coating or the content of neodymium to modify the spectrum to different degrees, and this modification changes the lumen output of the IRL. DOE assessed the efficacy differences between standard- and modified-spectrum IRL by measuring the efficacies of commercially-available standard- and modified-spectrum lamps. DOE correlated the measured color point data of the lamps with lamp light output reduction and lamp spectral power distribution. By analyzing the data, DOE established that a reduction of 15% from the standard-spectrum efficacy levels would be appropriate for modified-spectrum IRL. Table 5.5.8 shows a summary of the ELs for modified-spectrum IRL with diameters greater than 2.5 inches and operating voltages less than 125V. See appendix 5C for further details on DOE's modified-spectrum IRL analysis.

Table 5.5.8 Summary of the ELs for Modified-Spectrum IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Less Than 125V

EL	Efficacy Requirement (lm/W)		Reduction
	Standard Spectrum	Modified Spectrum	
1	$4.6P^{0.27}$	$3.9P^{0.27}$	15.0%
2	$4.8P^{0.27}$	$4.1P^{0.27}$	15.0%
3	$5.4P^{0.27}$	$4.6P^{0.27}$	15.0%
4	$5.9P^{0.27}$	$5.0P^{0.27}$	15.0%
5	$6.4P^{0.27}$	$5.4P^{0.27}$	15.0%

P = rated wattage

5.5.2.2 IRL With Diameters Less Than or Equal To 2.5 Inches

A smaller-diameter IRL has an inherently lower optical efficacy than a larger-diameter lamp given a similar filament size. To determine an appropriate scaling factor for IRL with diameters less than or equal to 2.5 inches, DOE examined the inherent efficacy differences between the PAR20 lamp and its PAR30 or PAR38 counterpart by comparing catalog efficacy data of each lamp type from several lamp manufacturers. In its analysis, DOE found that the reduction in efficacy caused by the reduction in lamp diameter was approximately 12 percent for IRL. DOE thus established EL1 through EL3 small-diameter IRL requirements that are 12 percent less than the efficacy requirements for large-diameter IRL.

DOE developed EL4 and EL5 for large-diameter IRL based on IRL that featured a double-ended HIR capsule. Single-ended capsules feature a lead wire inside of the capsule that carries current between the filament and the electrical connection in the IRL's base. The presence of this wire inside of the capsule prevents a certain amount of energy from reaching the capsule wall and being reflected (recycled) back to the capsule filament. A double-ended burner, on the other hand, features a lead wire outside of the capsule, where it does not interfere with the reflectance of energy from the capsule wall back to the capsule filament. The double-ended HIR capsule configuration does not generally fit into a PAR20 lamp due to its reduced size, however. Thus, DOE developed the EL4 and EL5 efficacy requirements for small-diameter IRL by assuming that the double-ended burner technology could not be used. In order to determine the efficacy reduction that would result from using a single-ended burner instead of a double-ended burner in a lamp, DOE obtained a commercially-available single-ended HIR capsule and measured the location of the lead wire inside of the capsule. DOE then developed a model that computed how much energy is prevented from being reflected against the capsule wall and recycled due the the "shadowing effect" of the lead wire inside of the capsule. DOE was also able to determine the slight change in IRL power consumption due to the reduction in energy recycling. Finally, DOE simulated manufacturing variability by modeling the effects of changing the capsule dimensions and lead wire positioning by small amounts. Using the modeled data, DOE computed that an efficacy reduction of approximately 3.5 percent would result from the usage of a single-ended burner instead of a double-ended burner in a lamp. This 3.5-percent reduction is in addition to the 12-percent-lower optical efficacy featured by small-diameter IRL in comparison with large-diameter IRL.

Table 5.5.9 shows a summary of the ELs for standard-spectrum IRL with diameters less than or equal to 2.5 inches and operating voltages less than 125V.

Table 5.5.9 Summary of the ELs for Standard-Spectrum IRL With Diameters Less Than or Equal To 2.5 Inches and Operating Voltages Less Than 125V

EL	Efficacy Requirement (lm/W)		Reduction
	≥ 2.5 Inches	< 2.5 Inches	
1	$4.6P^{0.27}$	$4.0P^{0.27}$	12.0%
2	$4.8P^{0.27}$	$4.2P^{0.27}$	12.0%
3	$5.4P^{0.27}$	$4.8P^{0.27}$	12.0%
4	$5.9P^{0.27}$	$5.0P^{0.27}$	15.5%
5	$6.4P^{0.27}$	$5.4P^{0.27}$	15.5%

P = rated wattage

5.5.2.3 IRL With Operating Voltages Greater Than or Equal to 125 Volts

As discussed in chapter 3, the Market and Technology Assessment, when operated under 120V conditions, lamps rated at 130V in compliance with existing IRL efficacy standards are generally less efficacious than lamps using equivalent technology rated at 120V. In consideration of the different test procedures for IRL rated at 130V than those rated at 120V, and by using published manufacturer literature, confidential information on incandescent design, and equations from the <u>IESNA Lighting Handbook</u>,[6] DOE derived an efficacy scaling factor which would result in equivalent performance of both classes of IRL when operating under the same voltage conditions (as they most often are). The equations DOE used from the IESNA lighting handbook are as follows:

$$\frac{life}{LIFE} = \left(\frac{VOLTS}{volts}\right)^d \qquad \textbf{Eq. 5.2}$$

$$\frac{lumens}{LUMENS} = \left(\frac{volts}{VOLTS}\right)^k \qquad \textbf{Eq. 5.3}$$

$$\frac{watts}{WATTS} = \left(\frac{volts}{VOLTS}\right)^n \qquad \textbf{Eq. 5.4}$$

Capital letters represent normal rated values while lower-case letters represent changed values. By using published manufacturer literature on IRL lumen, wattage, and voltage ratings, DOE found that the most typical values for d, k, and n in the above equations for the IRL analyzed are as follows: d=8.7, k=3.4, n=1.6. From this information and confidential information on incandescent lamp design, DOE was able to determine that a lamp operating at 130V would be 15-percent more efficacious than a lamp of a similar wattage operating at 120V. Therefore, DOE implements a 15-percent increase in the efficacy requirement for lamps rated with a voltage greater than or equal to 125V. Table 5.5.10 shows a summary of the ELs for standard spectrum IRL with diameters greater than 2.5 inches and operating voltages greater than or equal to 125V.

Table 5.5.10 Summary of the ELs for Standard Spectrum IRL With Diameters Greater Than 2.5 Inches and Operating Voltages Greater Than or Equal to 125V

EL	Efficacy Requirement (lm/W)		Increase
	< 125 Volts	≥ 125 Volts	
1	$4.6P^{0.27}$	$5.3P^{0.27}$	15.0%
2	$4.8P^{0.27}$	$5.5P^{0.27}$	15.0%
3	$5.4P^{0.27}$	$6.2P^{0.27}$	15.0%
4	$5.9P^{0.27}$	$6.8P^{0.27}$	15.0%
5	$6.4P^{0.27}$	$7.4P^{0.27}$	15.0%

P = rated wattage

5.6 SUMMARY OF ALL EFFICACY LEVELS FOR COVERED PRODUCTS

5.6.1 Summary of All Efficacy Levels for Covered GSFL

Table 5.6.1 shows a summary of the efficacy levels for all general service fluorescent lamps affected by this rulemaking. The table shows the ELs for GSFL with CCTs less than as well as greater than/equal to 4,500K; the table also shows the associated ELs for 2-foot U-shaped lamps. “N/A” is shown where no ELs exist, such as for T5 lamps (which do not have five ELs). Representative product classes are shown in grey squares.

Table 5.6.1 Summary of All Efficacy Levels for Covered GSFL

CCT	Lamp Type	Efficacy Level				
		1	2	3	4	5
≤ 4,500K	4-foot medium bipin	78	81	85	89	93
	2-foot U-shaped	70	72	76	84	87
	8-foot single pin slimline	86	92	95	97	98
	8-foot recessed double contact HO	83	86	88	92	95
	4-foot T5 miniature bipin SO	86	90	N/A	N/A	N/A
	4-foot T5 miniature bipin HO	76	N/A	N/A	N/A	N/A
> 4,500K	4-foot medium bipin	77	79	82	88	92
	2-foot U-shaped	65	67	71	81	85
	8-foot single pin slimline	83	87	91	93	94
	8-foot recessed double contact HO	80	83	84	88	91
	4-foot T5 miniature bipin SO	81	85	N/A	N/A	N/A
	4-foot T5 miniature bipin HO	72	N/A	N/A	N/A	N/A

5.6.2 Summary of All Efficacy Levels for Covered IRL

Table 5.6.2 shows a summary of the coefficients of the efficacy levels for all incandescent reflector lamps affected by this rulemaking. The various combinations of IRL features such as standard-spectrum vs. modified-spectrum, diameters greater than or less than/equal to 2.5 inches, and operating voltages greater than/equal to or less than 125V are shown in the table. The representative IRL product class is shown in grey squares.

Table 5.6.2 Summary of Coefficients for All Efficacy Levels for Covered IRL

Lamp Type	Diameter	Voltage	Efficacy Level				
			1	**2**	**3**	**4**	**5**
Standard-spectrum	> 2.5 inches	≥ 125V	5.3	5.5	6.2	6.8	7.4
		< 125V	4.6	4.8	5.4	5.9	6.4
	≤ 2.5 inches	≥ 125V	4.7	4.9	5.5	5.7	6.2
		< 125V	4.0	4.2	4.8	5.0	5.4
Modified-spectrum	> 2.5 inches	≥ 125V	4.5	4.7	5.3	5.8	6.3
		< 125V	3.9	4.1	4.6	5.0	5.4
	≤ 2.5 inches	≥ 125V	4.0	4.1	4.6	4.9	5.3
		< 125V	3.4	3.6	4.0	4.2	4.6

REFERENCES

[1] National Electrical Manufacturers Association. 2006. No. 12 at p. 7. This written comment, Document Number 12, is available in Docket #EE–2006–STD–0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[2] U.S. Department of Energy, Energy Efficiency and Renewable Energy Office of Building Research and Standards. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: Technical Support Document: Energy Efficiency Standards for Consumer Products: Fluorescent Lamp Ballast Proposed Rule. Appendix B. Marginal Energy Prices and National Energy Savings. Table B.6. January, 2000. Washington, D.C. <http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/appendix_b.pdf.

[3] Codes and Standards Enhancement (CASE) Initiative For PY2008: Title 20 Standards Development. Analysis of Standards Options for Linear Fluorescent Fixtures. Prepared for: PG&E Prepared by: ACEEE, Lighting Wizards, and Energy Solutions Last Modified: May 14, 2008.

[4] National Electrical Manufacturers Association. 2008. No. 26 at p. 7. This written comment, Document Number 26, is available in Docket #EE–2006–STD–0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[5] National Electrical Manufacturers Association. 2009. No. 37 at pp. 123-124. This public meeting transcript, Document Number 37, is available in Docket #EE–2006–STD–0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[6] Rea, M. S., ed., The IESNA Lighting Handbook: Reference and Application, 9th Edition. New York: Illuminating Engineering Society of North America. IESNA (2000).